Review of Options for Thermalito Afterbay Water Temperature Improvements

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Review of Options for Thermalito Afterbay Water Temperature Improvements

The Engineering and Operations Workgroup has looked at several actions that could be used to effect changes in water temperature in Thermalito Afterbay (afterbay). Some are intended to increase water temperature while others are intended to reduce water temperature. This write-up provides a list of the actions as well as background data on current afterbay water temperature conditions. Overall, the actions either (1) change the residence time in the afterbay, (2) change the location where diversions occur, or (3) change input temperatures to either diversions or the afterbay.

1. Resource Action Description:

Originally, this resource action was described as a series of open channel conveyance facilities (either canals and/or temperature curtains) from an area in the north western end of Thermalito Afterbay near Thermalito Pumping-Generating Plant to an area in the south western end of the afterbay near the Thermalito Afterbay Outlet. It would also include a system of small dams which are also proposed to develop pools that may provide cold water to the Feather River and warm water for agricultural diversions.

Other options were discussed in a subsequent E&O Workgroup brainstorming meeting and can be categorized into five basic groups:

- Methods to convey cold water to the afterbay outlet.
- Methods to convey warmer water to the afterbay agricultural diversion points.
- Methods to increase the residence time of water in the afterbay.
- Methods to warm the water that has already entered the diversion canals or has already been diverted to individual farms.
- Methods to change the input temperature of water entering the afterbay.

The following table summarizes the options that have been discussed.

Table 1 Options for Thermalito Afterbay Temperature Improvements

	Changes to the Oroville Facilities		Effects	
	Operational	Structural	Environmental	Power
A. Convey Cold Water to Thermalito Afterbay Outlet				
A.1 Route some or all of the water, to be released to the river, down the low flow channel rather than through the Thermalito Complex (May 1 through June 30)	X			X /e/
A.2 Construct canal outside of the Thermalito Afterbay to convey water directly from the Thermalito Power Plant to the Feather River	X	X	X /a/	X /e/
A.3 Install a suite of buried pipes in the Thermalito Afterbay to convey water directly from the Thermalito Power Plant to an area in the afterbay near the outlet structure		X	X /b/	
A.4 Dredge an underwater conveyance channel along the thalweg of the afterbay to the outlet (requires facilities to "lift" into outlet)	X	X	X /b/	
A.5 Install temperature curtain (to cool water) on the east side of Thermalito Afterbay		X	X	
A.6 Construct canal outside of Thermalito Afterbay to transport water into the aferbay at another location (presumably southeastern)		X		
A.7 Install a shear boom in front of the outlet structure to keep warmer water away from the outlet.		X		
B. Convey Warm Water to Agricultural Diversion Canals				
B.1 Draw warmer water for agricultural diversions	X		X /b/	
B.2 Install baffles to warm water in Thermalito Afterbay		X		
B.3 Install temperature curtain to warm water on west side of Thermalito Afterbay		X	X /b/	
B.4 Relocate Sutter Butte Canal Outlet		X		
B.5 Relocate Richvale Canal Outlet and Western Canal Outlet		X		
C. Increase Water Residence Time in Thermalito Afterbay				
C.1 Use baffles to re-direct return flow from conveyance structures.		X	X /b/	
C.2 Change agricultural demand to allow longer residence time	X			
C.3 Manage TAB for agricultural flows (maximize residence time, TAB levels, and baffles to force cold water away from Western Canal)	X	X	X	X /e/
C.4 Re-configure islands, by connecting them, in TAB to redirect water flow and increase residence time		X	X	
D. Increase Water Temperature After Delivery to Agricultural Diversion Canals				
D.1 Install power generation units (no head) at agricultural canal outlets to increase temperature		X	X	
D.2 Install solar panels on canals with strip heaters in water		X /h/	X /b/	
D.3 Install stand pipes at agricultural canal outlets		X	X	X /f/
D.4 Pump warm air into water to increase water temperature at diversions		X	X	X /f/
D.5 Construct and operate a co-generation plant on Western Canal (such a facility could use rice straw waste to increase water) temperature		X	X	
D.6 Warm agricultural diversion water by building warming ponds in canals		X /g/	X /b/	
D.7 Place pool solar blankets on TAB	X	X	X	
D.8 Develop "shallow" pond to warm water near north end of afterbay		X	X	
D.9 Develop warming checks at turnouts –purchase for ponding				
D.10 Pump groundwater from the Tuscan aquifer layer.				X /f/
E. Change Thermalito Afterbay Inflow Temperature				
E.1 Operate Hyatt Intake structure to provide warmer water from May 1 through June 30	X	X		

E.2 Operate chiller to cool Feather River Fish Hatchery water for egg incubation from May 1 through Jun 30	X	X		X /f/
E.3 Develop an alternative source of cold water for FRFH (i.e., Palermo Canal)	X	X	X	

/a/ Some impacts to vernal pools would be expected. Such footprint effects could be minimized and mitigated.
/b/ Would result in habitat effects during construction only.
/c/ Effects peaking operations only.
/d/ Effects pump-back operations.
/e/ Effects peaking and pump-back operations.
/f/ Would require electric service
/g/ Ponds would be located outside of Oroville Facilities' project boundaries.
/h/ No changes to Oroville Facilities but would require changes to diverters' canals.

2. Project Nexus:

Water temperatures in Thermalito Afterbay are contingent on the intake elevation of releases from Lake Oroville. Releases from the Oroville Facilities are determined based upon downstream and instream requirements, flood management criteria, and State Water Project operations in the Sacramento-San Joaquin Delta. Criteria that affect the inter-facility operations include fishery temperature objectives in the river and at the hatchery as well as delivery to Feather River Service Area and SWP contractors. Unfortunately, water temperature objectives for agricultural and fishery uses are not always compatible. This resource action explores ways that such incompatibility may be minimized.

3. Potential Benefits:

DWR will continue to work with State and federal fishery resource agencies to develop reasonable temperature objectives for the Feather River that provide benefits for aquatic species survival and their habitat, maintain suitable water temperatures during the rice germination period, and meet other SWP obligations.

It is likely that several of the options listed above in Table 1 would require isolatation of cold water that enters the afterbay through the Thermalito Pumping-Generating Plant for direct outflow through Thermalito Afterbay Outlet to the Feather River or allow for diversion of warmer water.

4. Potential Constraints:

Structural changes in the afterbay may have recreational as well as environmental effects that would have to be considered. In addition, construction associated with such changes would also have effects that would need to be studied.

5. Existing Conditions:

As noted above, DWR operates the Oroville Facilities as part of the State Water Project to provide water supply. Decisions regarding releases from the Oroville Facilities are subject to many considerations. These include flood control criteria, delivery of water to local agencies, as well as in-stream and downstream requirements. The power operations of the facilities are subject to the constraints identified above. The power

operations are further constrained by inter-facility and in-stream fishery objectives. The fishery criteria include:

- Minimum river flow criteria and hatchery water temperature objectives. These are contained in an August 1983 agreement between DWR and the Department of Fish and Game entitled, "Agreement Concerning the Operation of Oroville Division of the State Water Project for Management of Fish & Wildlife." The 1983 agreement sets criteria and objectives for flow and temperatures in the low flow channel of the Feather River above Thermalito Afterbay and the reach of the Feather River between Thermalito Afterbay and Verona. The temperature objectives for the Feather River Fish Hatchery are summarized below.

Table 1. Feather River Fish Hatchery Water Temperature Objectives

Period	Temperature (+/- 4°F)
April 1 – May 15	51°
May 16 – May 31	55°
June 1 – June 15	56°
June 16 – August 15	60°
August 16 – August 31	58°
September 1 – September 30	52°
October 1 – November 30	51°
December 1 – March 31	No more than 55°

Source: Draft Application for New License, FERC Project No. 2100, Volume I, April 2004

- Maximum daily water temperature objective in the Low Flow Channel of the Feather River. The National Oceanic and Atmospheric Administrations (NOAA) Fisheries (formerly National Marine Fisheries Service) established an explicit objective for salmonids. Memorialized in a biological opinion on the effects of the Central Valley Project and SWP on Central Valley spring-run Chinook and steelhead as a reasonable and prudent measure; DWR is required to target water temperature at Feather River mile 61.6 (Robinson's Riffle in the low-flow channel) from June 1 through September 30. This objective calls for water temperatures less than or equal to 65^{o}F on a daily average.

In May 2002, DWR began collecting water temperature data in Thermalito Afterbay. Water temperature monitoring stations were placed at Thermalito Pumping-Generating Plant tailrace, Richvale Canal, Western Canal Lateral, Western Canal Main, Sutter Butte Canal, and Thermalito Afterbay Outlet. Figure 1 shows the temperature monitoring station locations for the Oroville Facilities as well as Thermalito Afterbay.

DWR has a complete data set for Thermalito Afterbay water temperatures at each facility mentioned above for calendar year 2003. There were some missing data for Thermalito Afterbay water temperatures for calendar year 2002. Thermalito Afterbay average daily temperatures and diversion flows for July and August for calendar year 2002 are shown in Appendix A.

Actual water temperature data obtained for each monitoring station show cooler water in May 2003 overall and a warming trend typically begins in June 2003 and continues through August 2003.

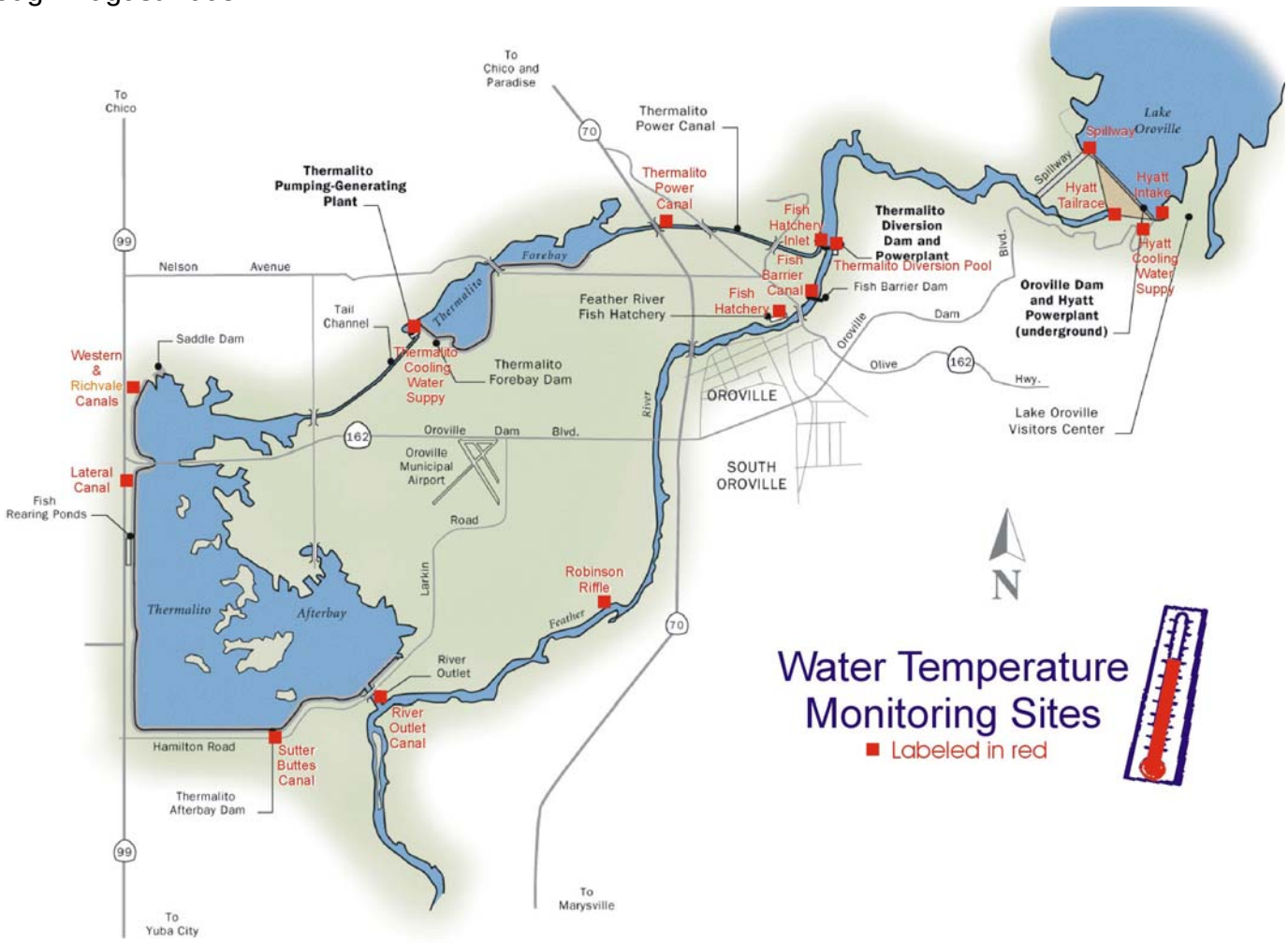


Figure 1. Temperature Monitoring Stations

The data also show that as diversions increase over a period of several days that the water temperature at the agricultural diversion points decrease; this is particularly apparent at the Western Lateral Canal diversion as shown in Appendix B. The water temperature decreases suggest the warmer water is getting replaced by colder reservoir

releases that are necessary to meet agricultural diverters' increasing water demands from Thermalito Afterbay.

Figure 2 below shows the actual average daily water temperatures for Sutter Buttes Canal, Western Canal, and Thermalito Afterbay Outlet for May 2003.

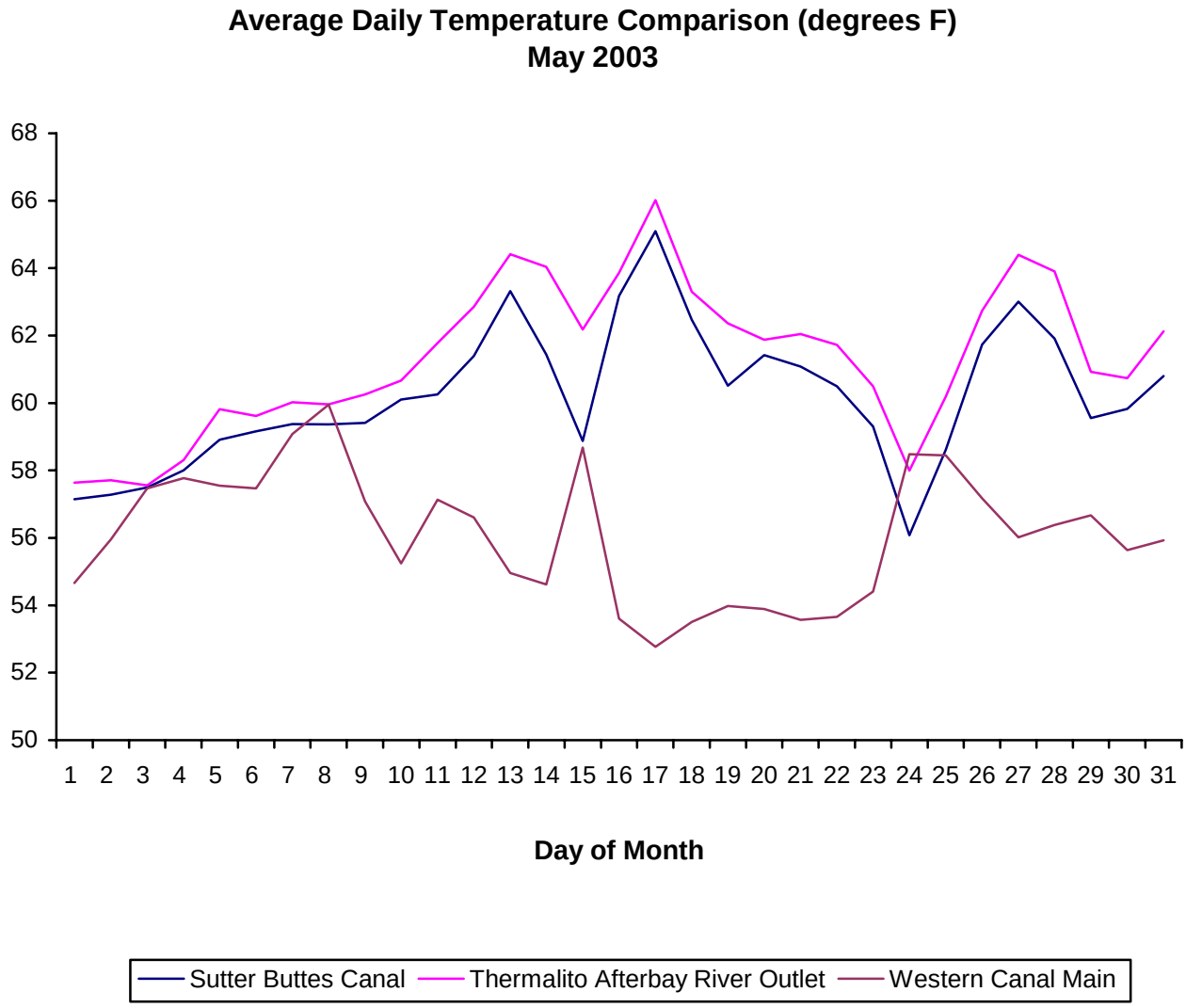


Figure 2. Average Daily Temperature Comparison for May 2003

The average daily water temperature for Sutter Buttes Canal seems to track relatively closely with the temperatures of Thermalito Afterbay Outlet. Differences in average daily temperatures between Western Canal Main and Thermalito Afterbay Outlet can, for the most part, be described as representing a diverging trend. The maximum average daily temperature differences range between about 4 ^{o}F and 14 ^{o}F. DWR staff believes meteorology data play a significant role in water temperature conditions early

in the spring when air temperatures remain relatively low. Therefore, residence time may not increase water temperatures in the afterbay. As spring air temperatures increase, residence time in Thermalito Afterbay becomes an important factor on whether water temperatures are either cool or warm. In other words, when warmer weather conditions exist, longer water residence time will help raise water temperatures to levels suitable for agricultural diversions from Thermalito Afterbay. Since spring-time ambient temperatures can vary greatly, options that effect a change in the afterbay input temperature would have a greater effect than options that increase residence time. Thus, it may be necessary to consider several different options to achieve the desired effects.

A different pattern for the average daily water temperature difference is observed for June 2003 and is shown in Figure 3 below.

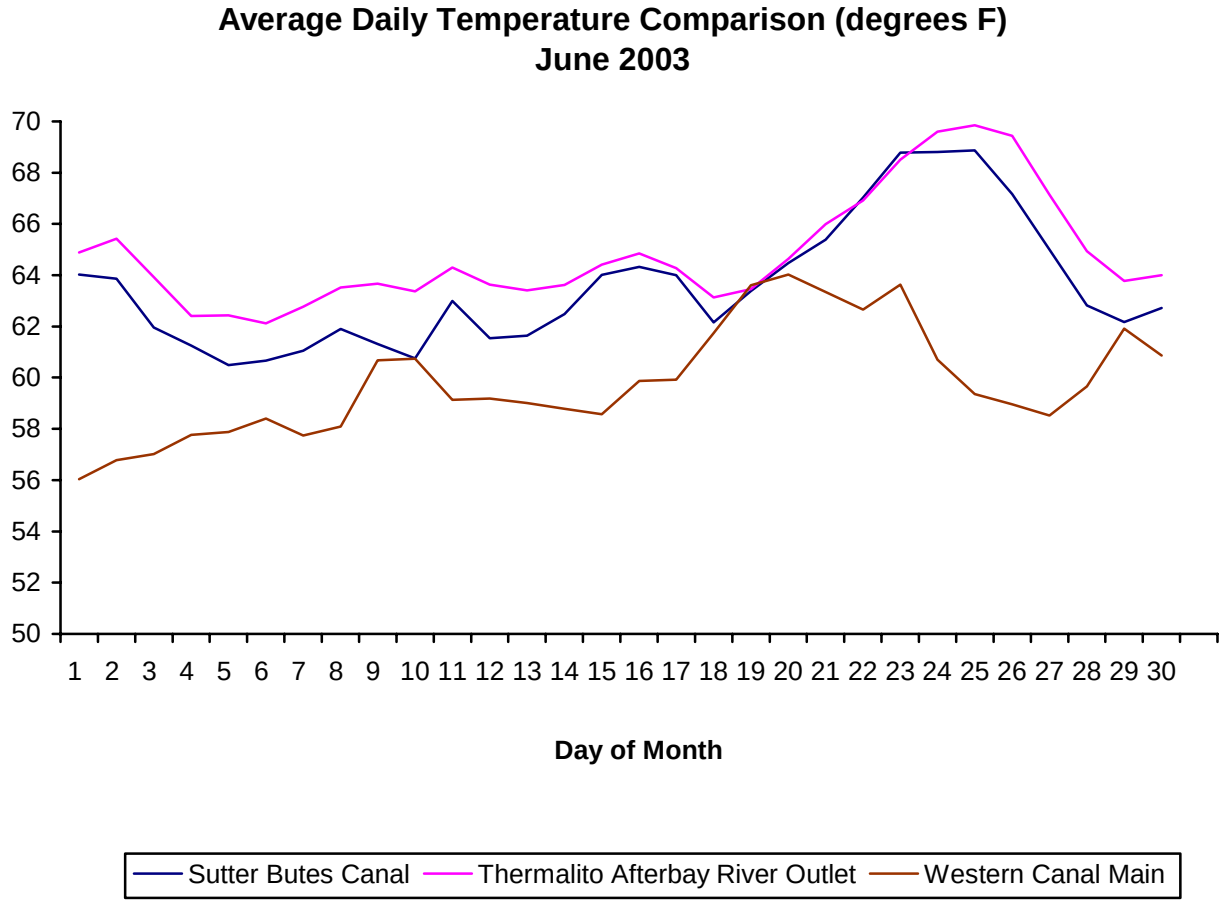
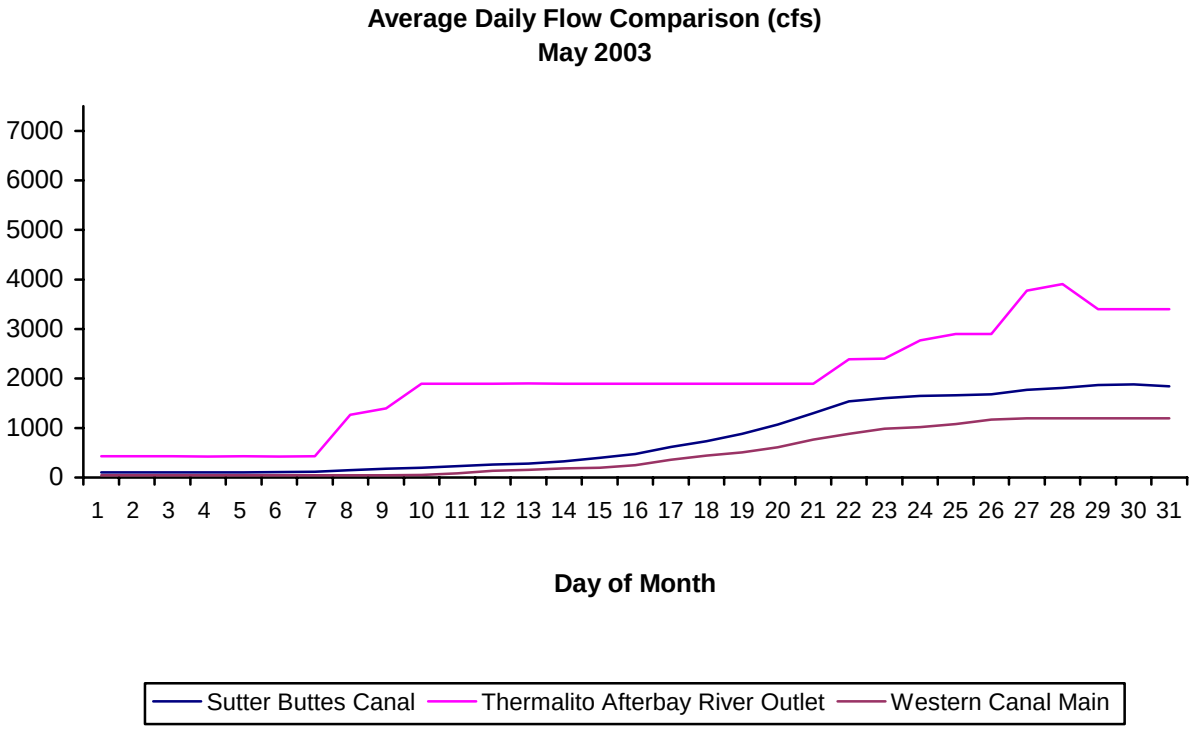


Figure 3. Average Daily Temperatue Comparison for June 2003

It appears that when agricultural diversions increased during June 2003, water temperatures remained cool due to subsequent shorter water residence time in

Thermalito Afterbay. Measured water temperatures at Thermalito Afterbay Outlet seem to be generally warmer than those at the Sutter Buttes Canal and Western Canal Main.

The average daily diversion flows for May 2003 and June 2003 are shown in Figure 4 below.



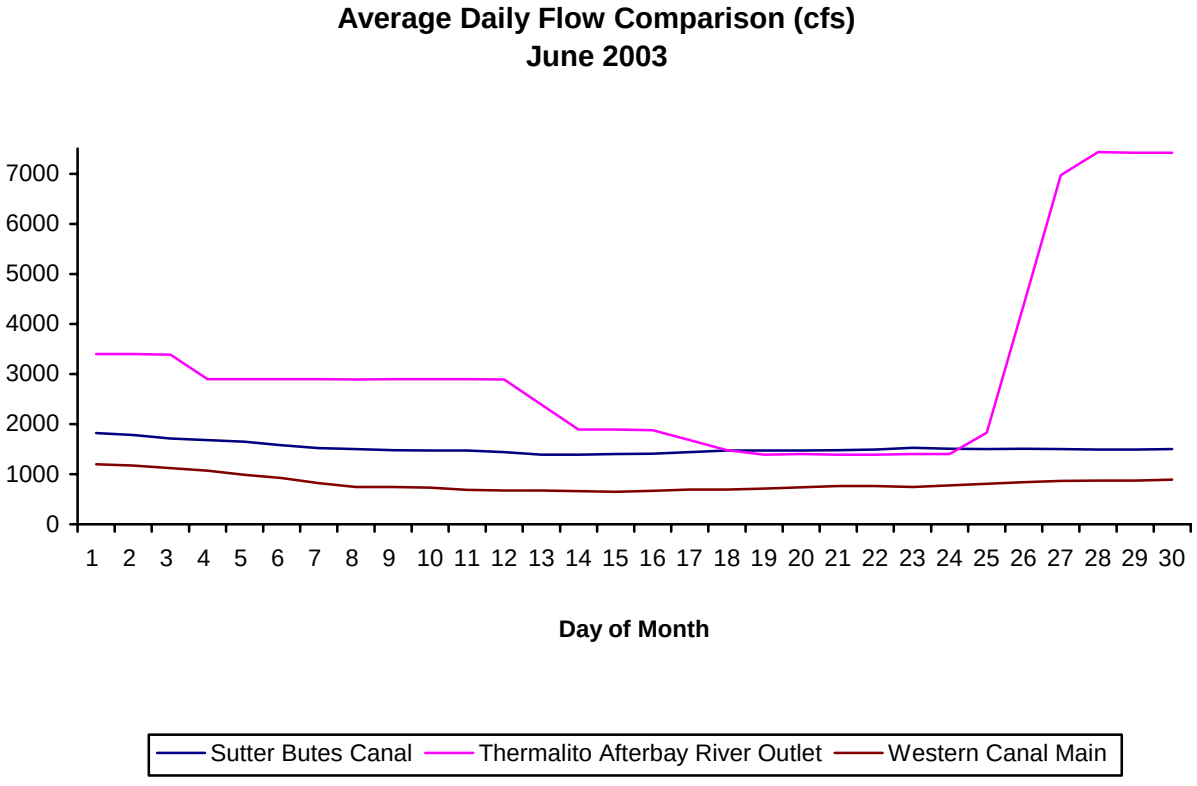


Figure 4. Average Daily Flow Comparisons for May and June 2003

Appendix C shows Western Canal's, Sutter Buttes Canal's, and Thermalito Afterbay Oulet's average daily temperatures and diversion flows for May through August for calendar year 2003.

DWR also compared mean daily air temperature data with water temperature data for Thermalito Afterbay's agricultural diversions for 2002 and 2003; these data were presented at DWR's Oroville Facilities Relicensing program's Operations Modeling Workshop #5. The data are provided in Appendix D. Air temperature data were provided in Appendix D to indicate whether a correlation exists between air and water temperature conditions.

6. Design Considerations and Evaluation:

Originally, this resource action write-up was to explore changes in water temperature conditions associated with a system of structures to convey water from the Thermalito Pumping-Generating Plant to an area in Thermalito Afterbay near the river outlet. DWR's Division of Engineering performed an initial estimate of cost for several design options for such structures. The initial cost estimates developed by DOE represent an order of magnitude estimation and do not consider all of the options presented in Table 1. The cost information along with the water and air temperature data that have been collected in the field are the basis for a reconnaissance-level evaluation of the potential improvements in water temperatures. Other reconnaissance-level analyses regarding environmental and recreational impacts may be necessary before staff could provide a recommendation to DWR management. Still, on the basis of potential changes in water temperature, one or more of the options described in this resource action's write-up shows promise.

DOE's analyses of construction costs suggest that conveyance facilities range between $14 million and $22 million. Below are brief descriptions of the options that were analyzed.

- Segregate cold water from the rest of the afterbay. The first design option proposes construction of a temperature curtain along the eastern edge of Thermalito Afterbay. The initial cost estimate is approximately $15 million.

- Construct canals to convey some of the water. The second and third design options propose construction of open conveyance channels to re-direct water from the northernmost portion of the afterbay to a region closer to Thermalito Afterbay Outlet. The second design option includes a lined channel and, the third design option's channel is unlined. The channels would be large enough to convey all of the water that is destined for release to the river about 80% of the time. However, some water would overflow into the northern portion of the afterbay during peaked operations. Initial cost estimates for the second and third design options are approximately $14 million and $11 million, respectively.
- Construct canals to convey all of the water. These options are the same as the set above except the canals would be capable of conveying the full capacity of

the power plant. The initial cost estimate for these options are $22 million and $18 million, respectively.

Based upon the assumption that it would be desirable to convey cold water more efficiently to the Thermalito Afterbay Outlet, any of the above options could merit further study and analyses. However, it is believed that all of the options above would potentially reduce the temperature of water diverted at Sutter Buttes Canal. Therefore, these options would likely need to be paired with options to convey warmer water to the agricultural diversion points. Figure 5 shows an example how two options could be combined to both reduce the temperature of water released to the river while avoiding significant reductions in water temperatures to agricultural diversions[1].

[1] In fact, this example would likely result in warmer water being diverted at Western Canal during the summer months.

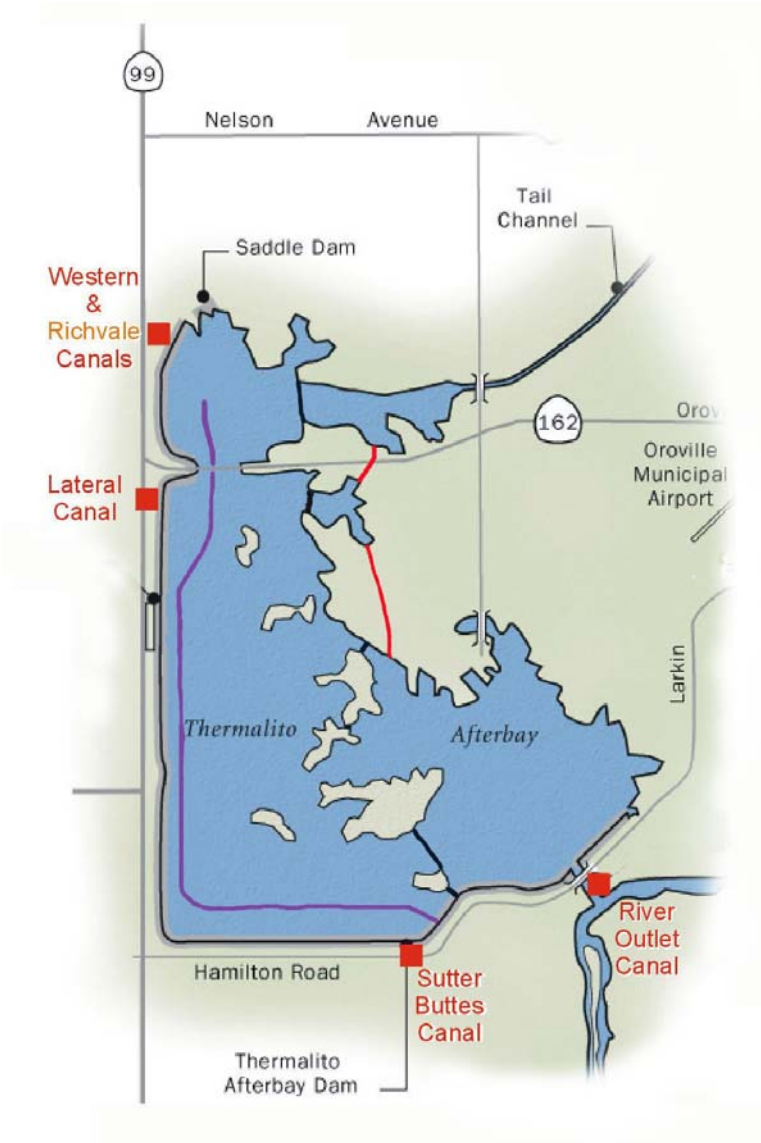


Figure 5. Example of the Thermalito Afterbay with Two Open Channel Conveyance Facilities, Temperature Curtain, and Dams

Synergism and Conflicts:
Combinations of options identified in this write-up could improve water temperatures from Thermalito Afterbay Outlet for aquatic species while potentially improving water temperatures for the benefit of agricultural diversions from Thermalito Afterbay.

Environmental impacts related to construction activities would have to be analyzed as well as potential mitigation options. For example, numerous vernal pools exist on the east side of the afterbay and could be disturbed by construction activities.

Recreation activities in the Afterbay may also be impacted due to many of the options listed above. Public safety issues must also be considered and analyzed regarding this proposed resource action.

7. Uncertainties:

There is no guarantee that construction of facilities would meet the desires of all parties interested in specific temperature objectives associated with Thermalito Afterbay water temperatures.

An economic analysis considering the financial and environmental, recreation, engineering, power, etc. effects is not included in this write-up.

8. Cost Estimate:

DWR's Division of Engineering is currently reviewing the cost of several options for designing the proposed open channel conveyance facilities and system of small dams. Initial cost estimate information is discussed above under section six.

9. Recommendations:

The E&O Workgroup met on May 21 and reviewed the list of options developed during the brainstorming meeting. Table 3 contains a list of recommendations from the Workgroup regarding further evaluation of specific options.

Table 3 Refining the Options for Thermalito Afterbay Temperature Improvements

	Recommend for Further Consideration/Analyses	
	Yes	Not at this time
A. Convey Cold Water to Thermalito Afterbay Outlet		
A.1 Route some or all of the water, to be released to the river, down the low flow channel rather than through the Thermalito Complex (May 1 through June 30)	X	
A.2 Construct canal outside of the Thermalito Afterbay to convey water directly from the Thermalito Power Plant to the Feather River.		X /a/
A.3 Install a suite of buried pipes in the Thermalito Afterbay to convey water dirclty from the Thermalito Power Plant to an area in the afterbay near the outlet structure.		X /b/
A.4 Dredge an underwater conveyance channel along the thalweg of the afterbay to the outlet (requires facilities to "lift" into outlet)	X	
A.5 Install temperature curtain (to cool water) on the east side of Thermalito Afterbay	X	
A.6 Construct canal outside of Thermalito Afterbay to transport water into the aferbay at another location (presumably southeastern)	X	
A.7 Install a shear boom in front of the outlet structure to keep warmer water away from the outlet.	X	
B. Convey Warm Water to Agricultural Diversion Canals		
B.1 Draw warmer water for agricultural diversions		X /c/
B.2 Install baffles to warm water in Thermalito Afterbay	X	
B.3 Install temperature curtain to warm water on west side of Thermalito Afterbay	X	
B.4 Relocate Sutter Butte Canal Outlet		X /d/
B.5 Relocate Richvale Canal Outlet and Western Canal Outlet		X /d/
C. Increase Water Residence Time in Thermalito Afterbay		
C.1 Use baffles to re-direct return flow from conveyance structures.	X	
C.2 Change agricultural demand to allow longer residence time in the afterbay.		X /e/
C.3 Manage TAB for agricultural flows (maximize residence time, TAB levels, and install baffles to force cold water away from Western Canal)	X	
C.4 Re-configure islands, by connecting them, in TAB to redirect water flow and increase residence time	X	
D. Increase Water Temperature After Delivery to Agricultural Diversion Canals		
D.1 Install power generation units (no head) at agricultural canal outlets to increase temperature		X /f/
D.2 Install solar panels on canals with strip heaters in water		X /g/
D.3 Install stand pipes at agricultural canal outlets		X /h/
D.4 Pump warm air into water to increase water temperature at diversions		X /i/
D.5 Construct and operate a co-generation plant on Western Canal (such a facility could use rice straw waste) to increase water temperature		X /j/
D.6 Warm agricultural diversion water by building warming ponds in canals		X /k/
D.7 Place pool solar blankets on TAB		X /l/
D.8 Develop "shallow" pond to warm water near north end of afterbay	X	
D.9 Develop warming checks at turnouts –purchase for ponding	X	
D.10 Pump groundwater from the Tuscan aquifer layer.	X	
E. Change Thermalito Afterbay Inflow Temperature		
E.1 Operate Hyatt Intake structure to provide warmer water from May 1 through June 30	X	
E.2 Operate chiller to cool Feather River Fish Hatchery water egg	X	

incubation from May 1 through Jun 30		
E.3 Develop an alternative source of cold water for FRFH (i.e. Palermo Canal)	X	

Comments on why specific options are not to be considered or analyzed at this time:

/a/: Similar to other options.

/b/: Releases to the Feather River during the summer months range from a low of about 1,700 cfs to over 9,000 cfs. Generally (about 60% of the time) the releases will be 6,000 cfs or less. However, peaking for power generation will increase the release from the Thermalito Power Plant to near capacity during high demand periods and to near zero during low demand periods. As a result, flows to the river would still have to be augmented during low demand periods while most of the water flowing from the power plant would have to be contained in the afterbay during how demand periods.

/c/: With only 4300 surface acres, the top foot of water would be drawn into the diversions in less than a day.

/d/: Option B.3 provides the same benefit but with lower cost and less impacts.

/e/: Difficult, if impossible, to change agricultural demand patterns sufficiently to allow for warming in the afterbay. In addition, as noted earlier in the text, residence time is not an effective means to warm water during the spring-time in many years.

/f/: The workgroup believes this option is not economical. Furthermore, it impedes flows in canals.

/g/: The workgroup believes this option is not economical and affects ability to properly maintain canals.

/h/: The workgroup believes this option is not economical. Both Western Canal and Sutter Butte Canal divert a large volume of water each day. At the peak diversion, nearly 3,500 cfs will be diverted at both canals. With that amount of water entering the canals, stand pipes would have to be enormous in order to provide sufficient surface area to have an appreciable effect on water temperature.

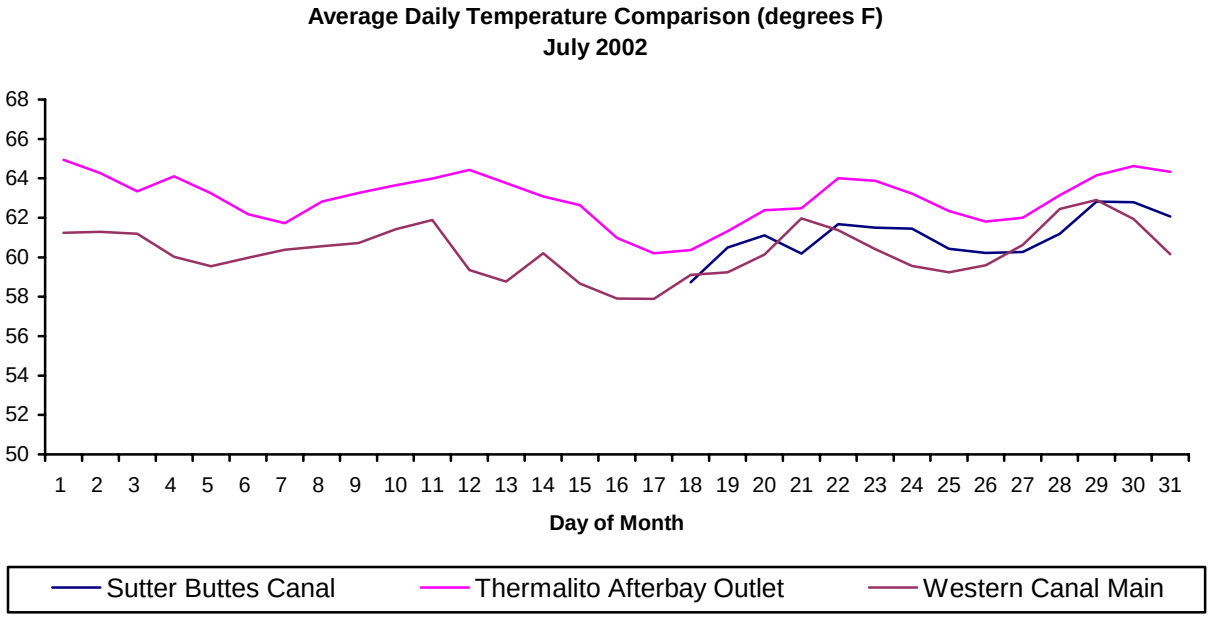
/i/: Similar comment as /h/.

/j/: Butte County could provide additional analyses for this option.

/k/: May not provide sufficient surface area to warm water.

/l/: Solar blankets covering the afterbay would impact recreation as well as fish and wildlife use of the afterbay. In addition, it would make operations and maintenance of the afterbay difficult and could pose a safety hazard by impeding normal inspection of facilities.

Appendix A
Thermalito Afterbay
Average Daily Temperature and Flow Comparison
July 2002
August 2002



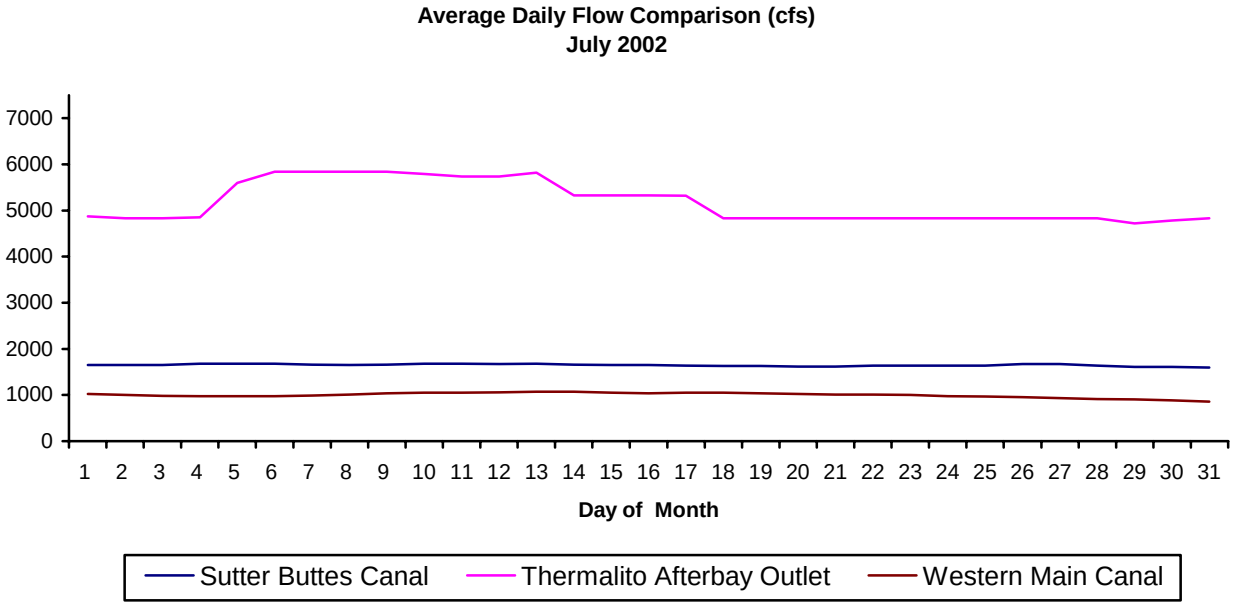
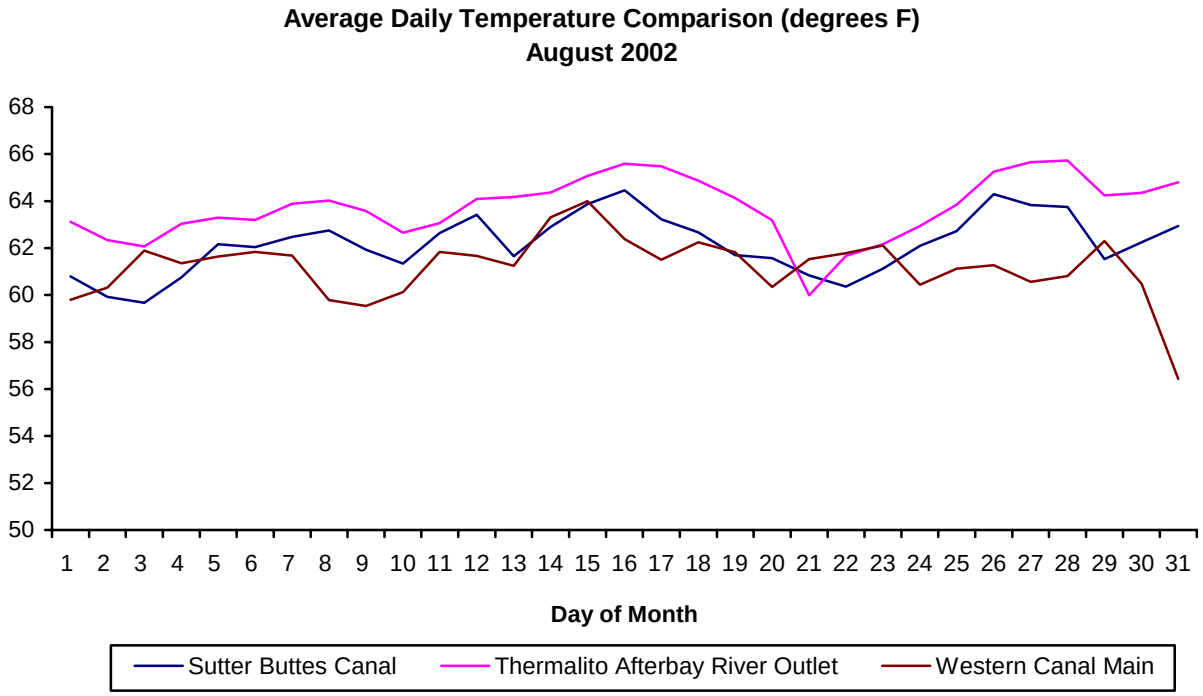


Figure A.1 Average Daily Temperature and Flow Comparison for July 2002



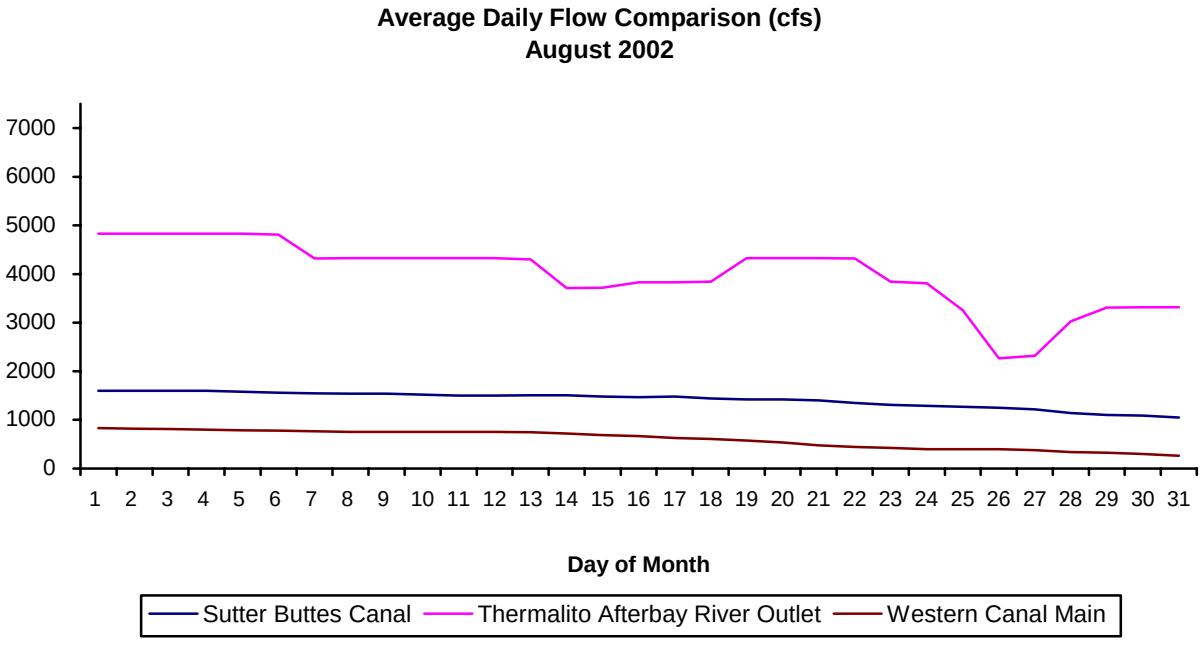
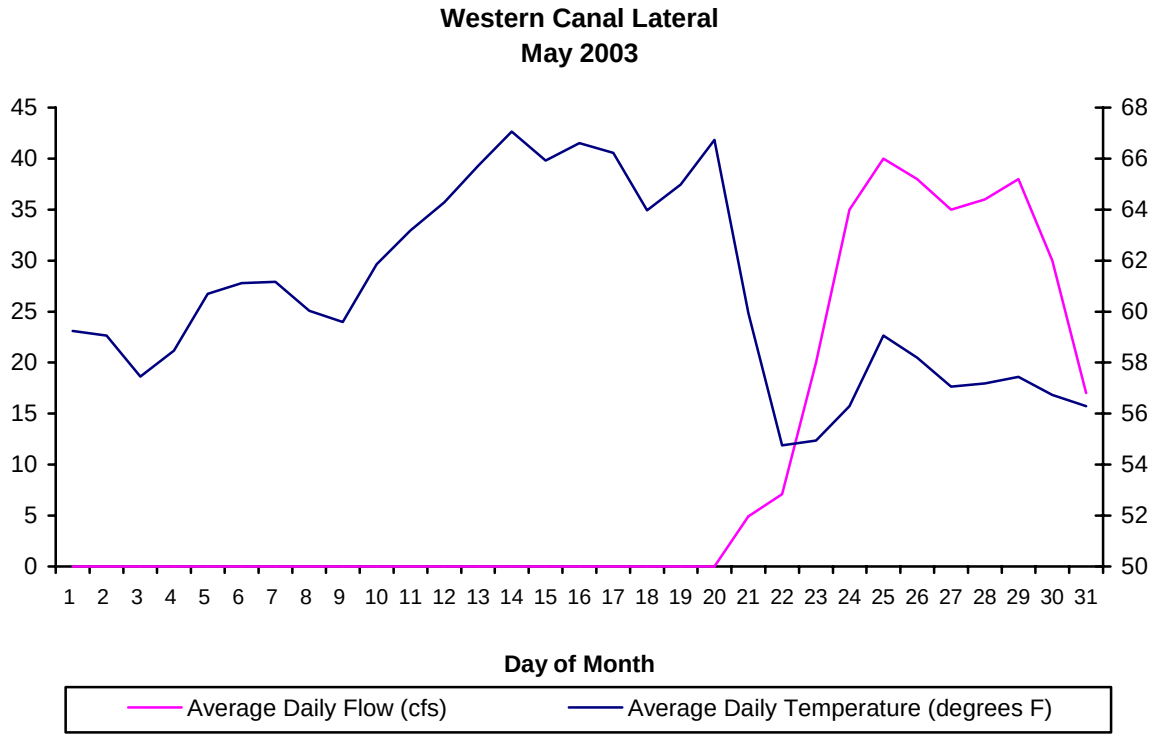


Figure A.2 Average Daily Temperature and Flow Comparison for August 2002

Appendix B
Western Canal Lateral
Average Daily Temperature and Flow Comparison
May 2003
June 2003
July 2003
August 2003



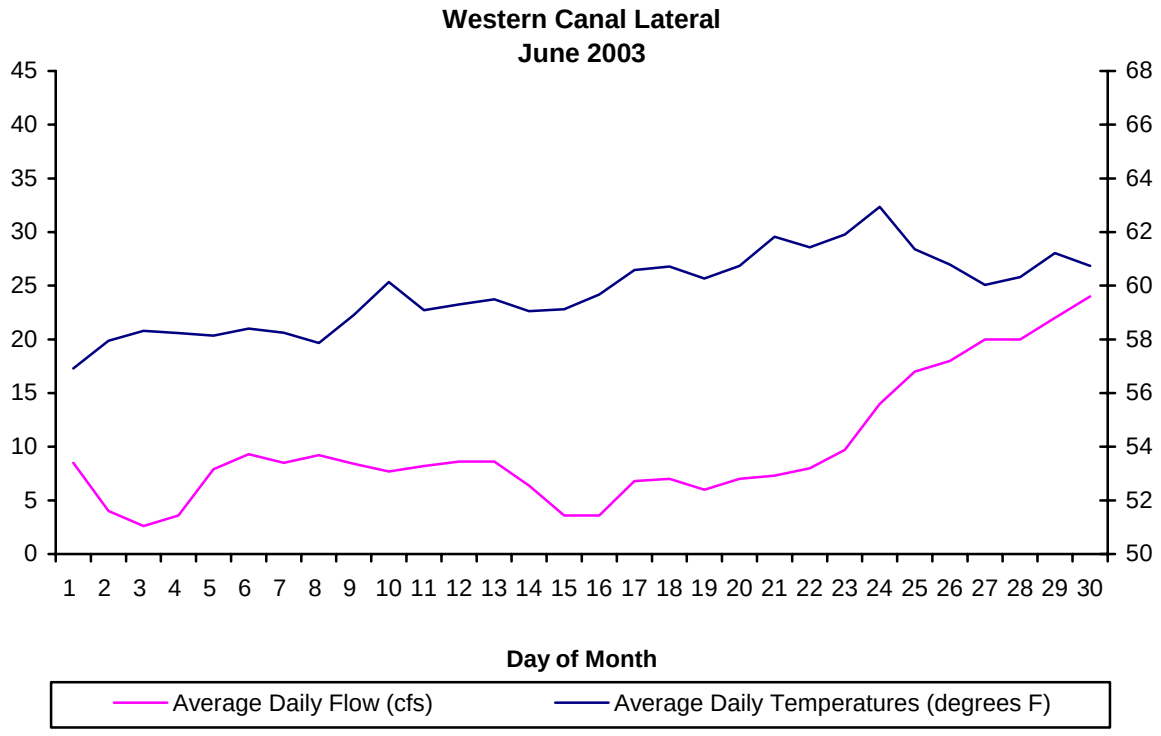
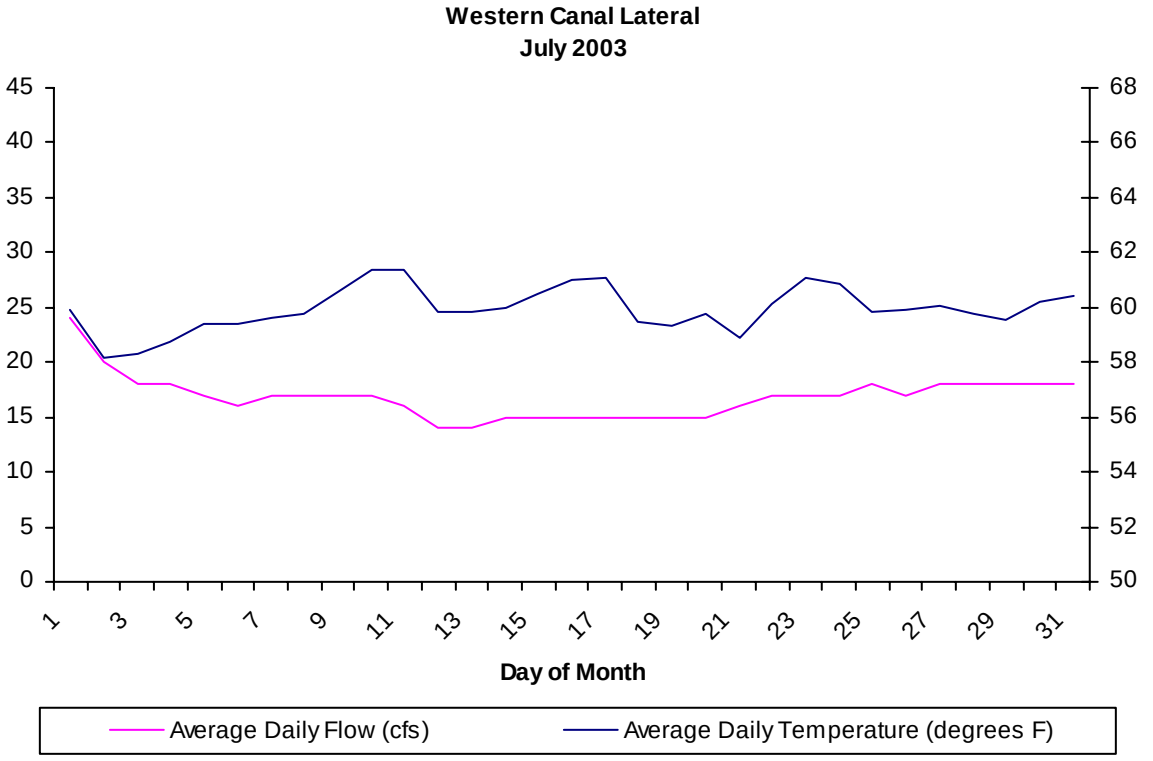


Figure B.1 Western Canal Lateral Temperature and Flow Comparison for May and June 2003



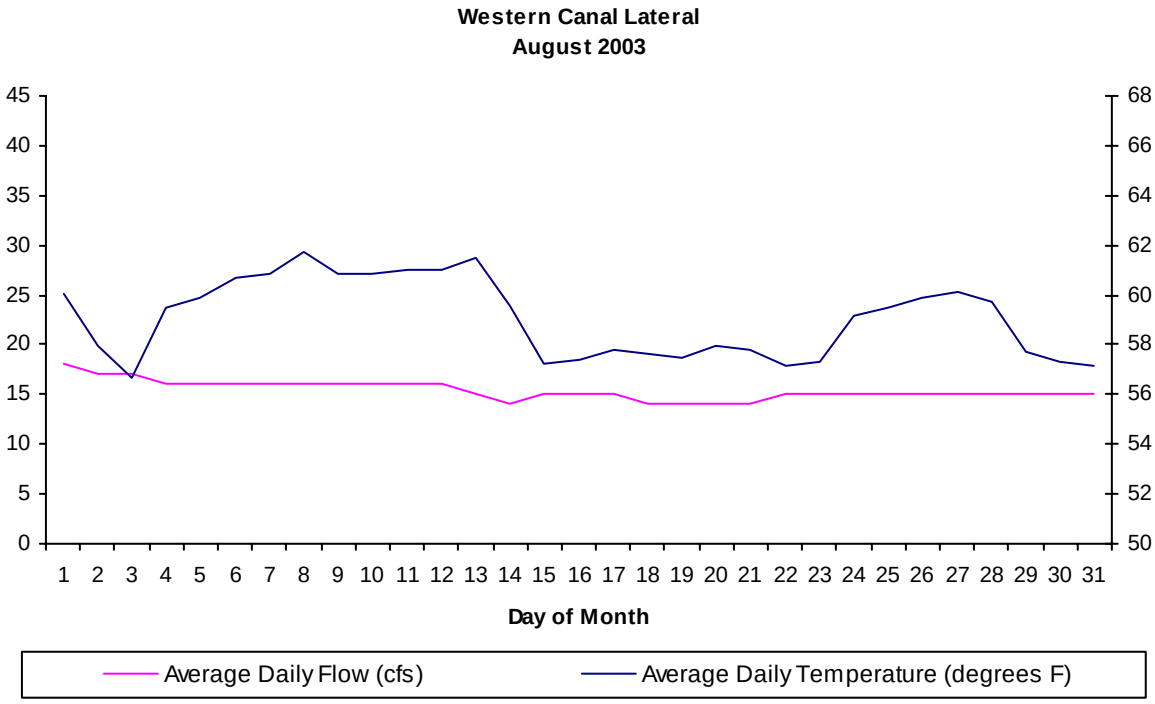
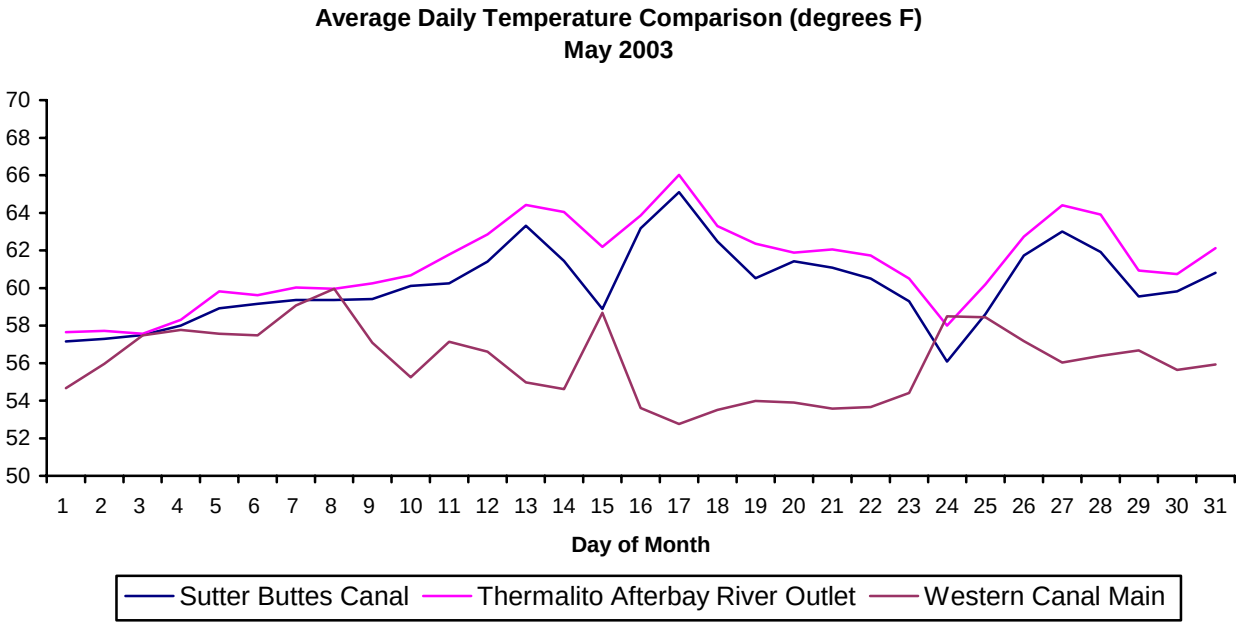


Figure B.2 Western Canal Lateral Temperature and Flow Comparison for July and August 2003

Appendix C
Western Canal Main
Sutter Buttes Canal
Thermalito Afterbay Outlet
Average Daily Temperature and Flow Comparison
May 2003
June 2003
July 2003
August 2003



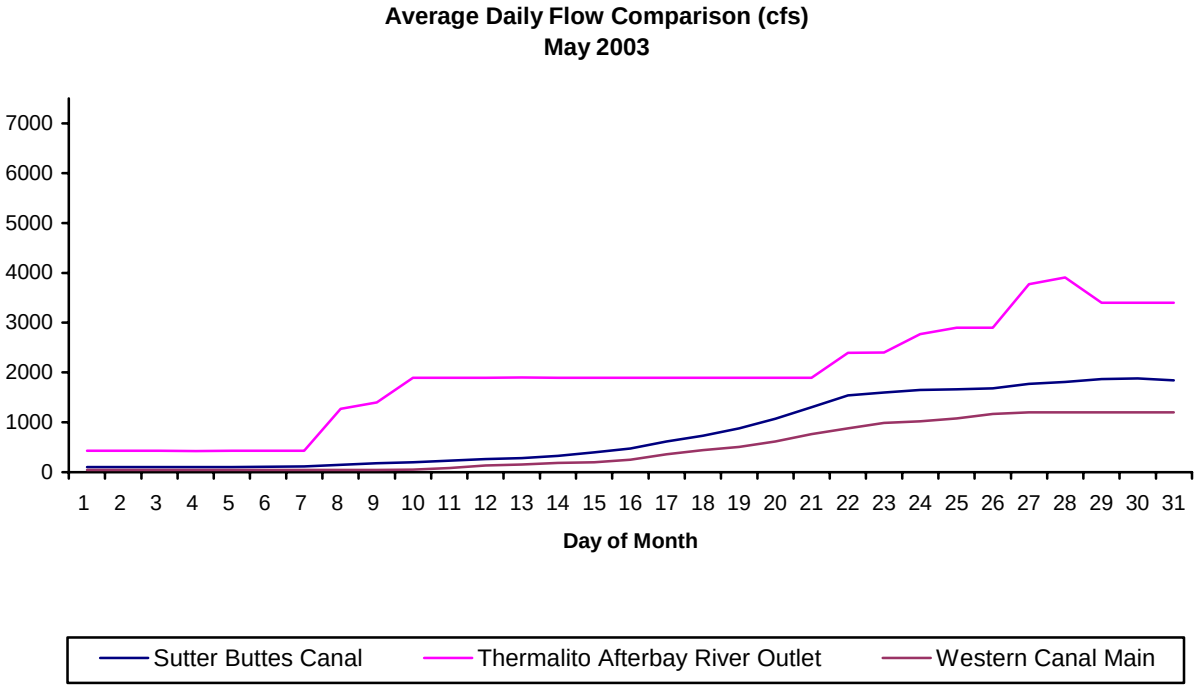
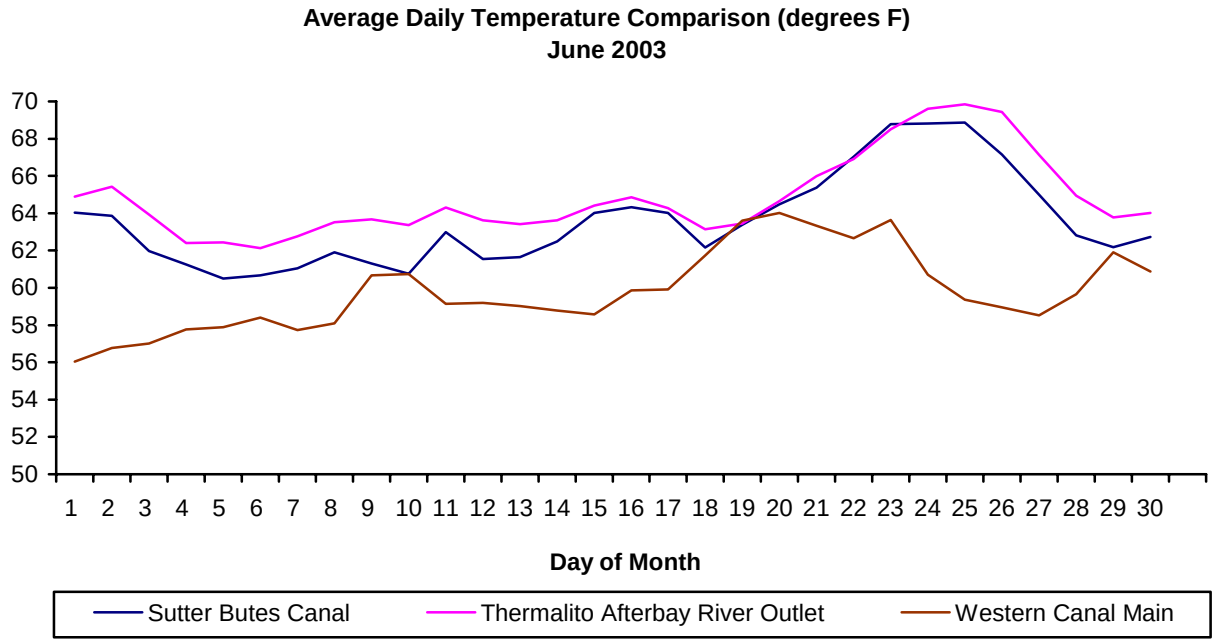


Figure C.1 Average Daily Temperature and Flow Comparison for May 2003



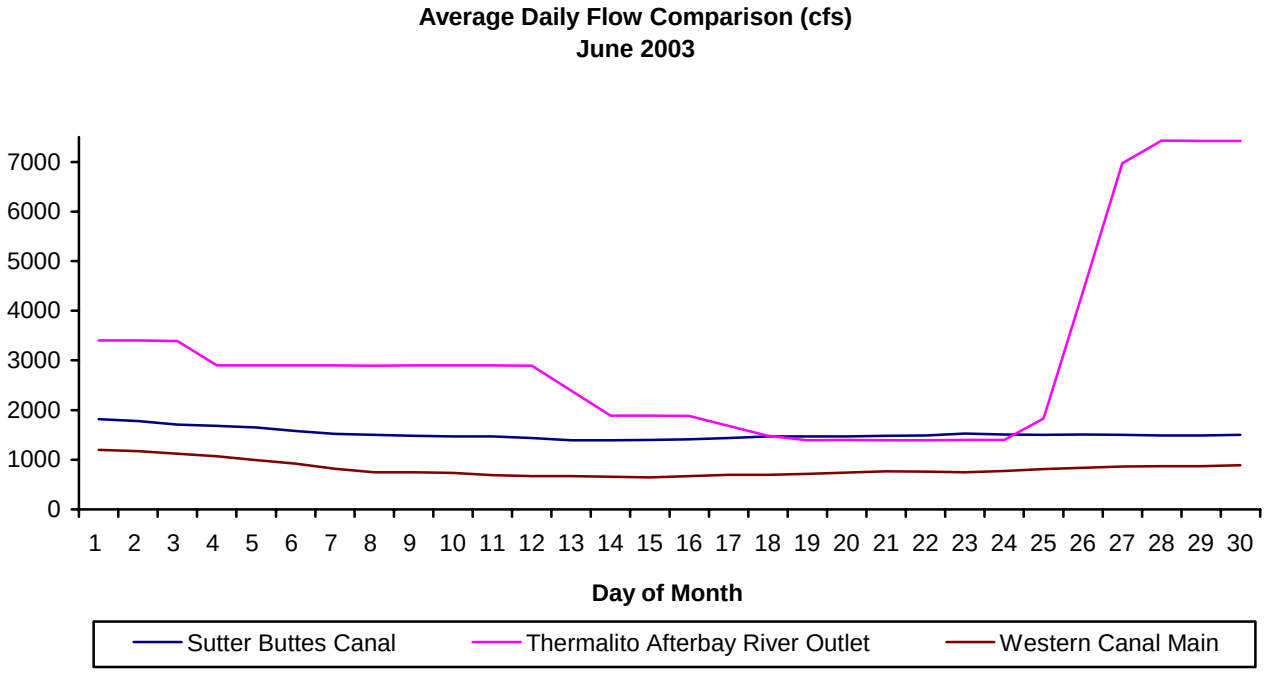
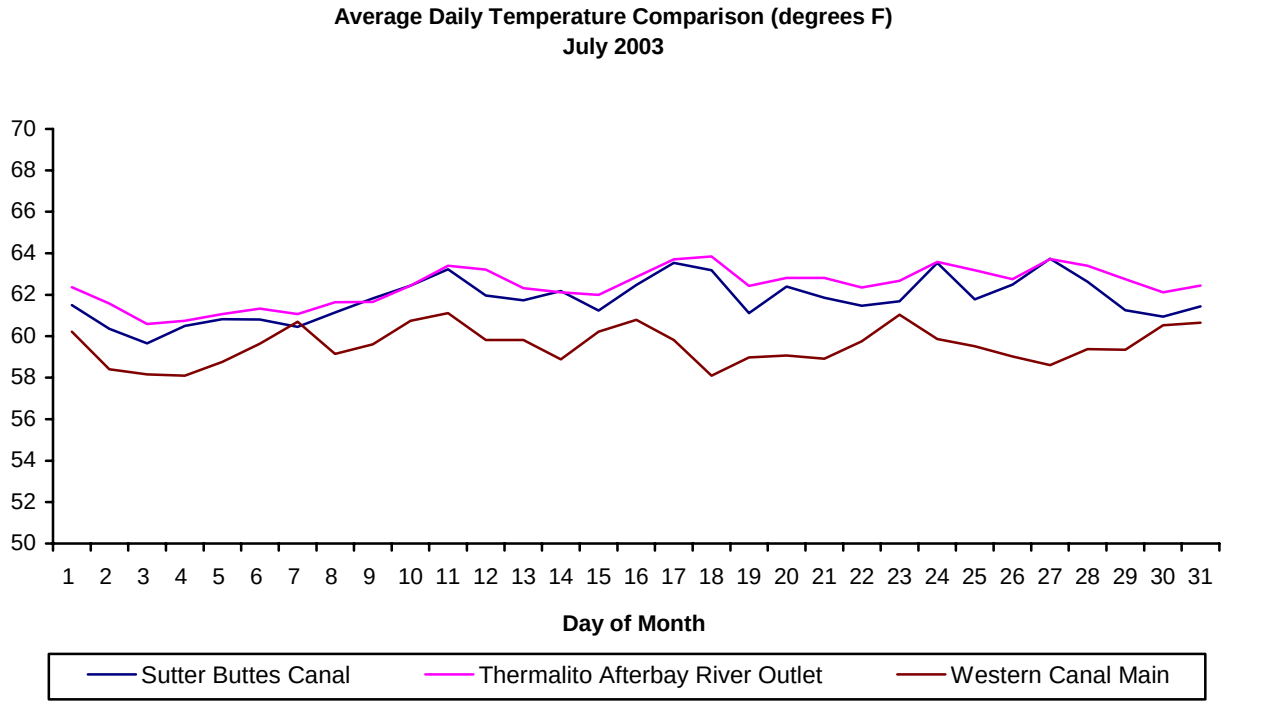


Figure C.2 Average Daily Temperature and Flow Comparison for June 2003



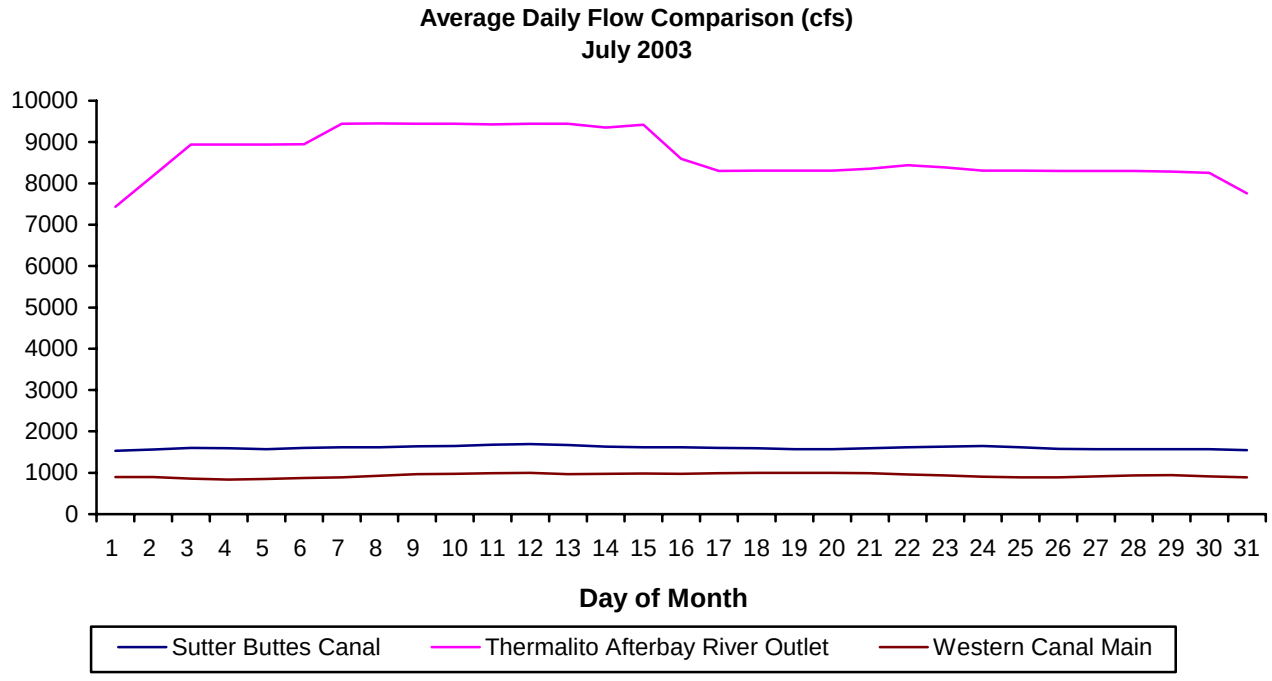


Figure C.3 Average Daily Temperature and Flow Comparison for July 2003

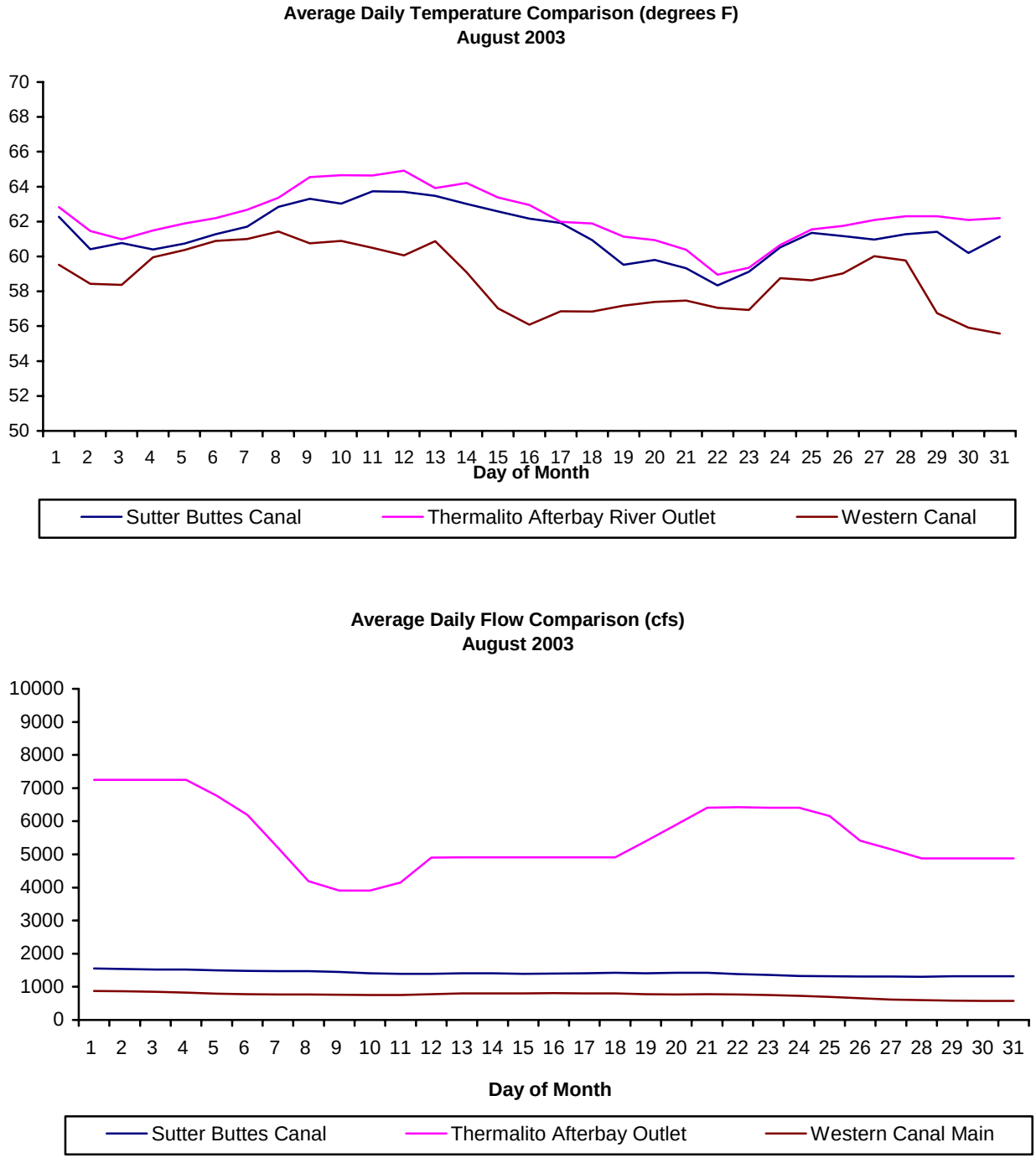


Figure C.4 Average Daily Temperature and Flow Comparison for August 2003

Appendix D

Afterbay Release Temperatures in Early 2002
Afterbay Release Temperatures during Growing Season 2002
Effects of Discharge in Western Canal Early 2002
Effects of Discharge on Temperatures during Growing Season 2002
Effects of Discharge on Temperatures in Early 2002

Afterbay Release Temperatures in Early 2003
Afterbay Release Temperatures during Growing Season 2003
Effects of Discharge in Western Canal Early 2003
Effects of Discharge on Temperatures during Growing Season 2003
Effects of Discharge on Temperatures in Early 2003

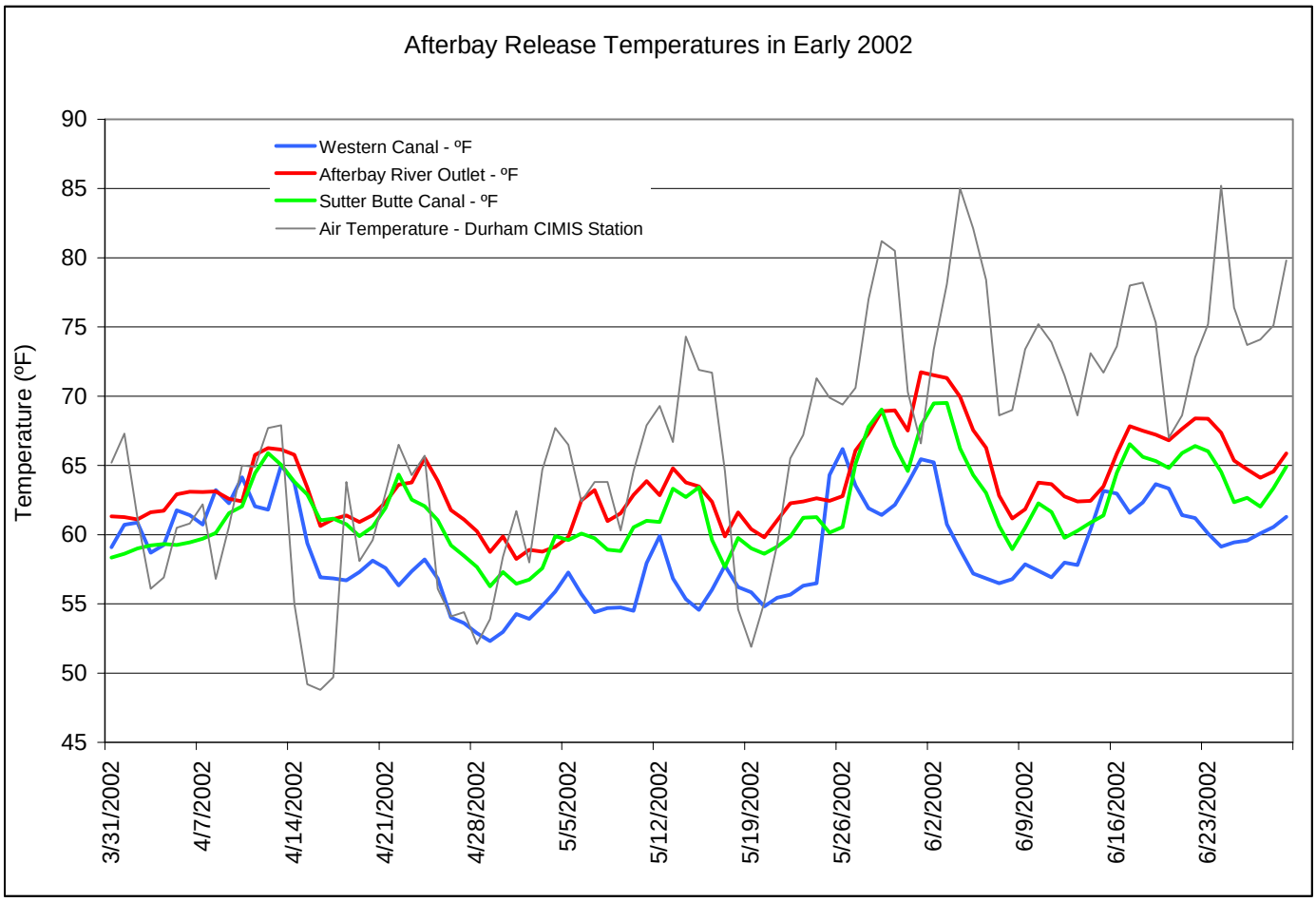


Figure D.1 Thermalito Afterbay Release Temperatures in Early 2002

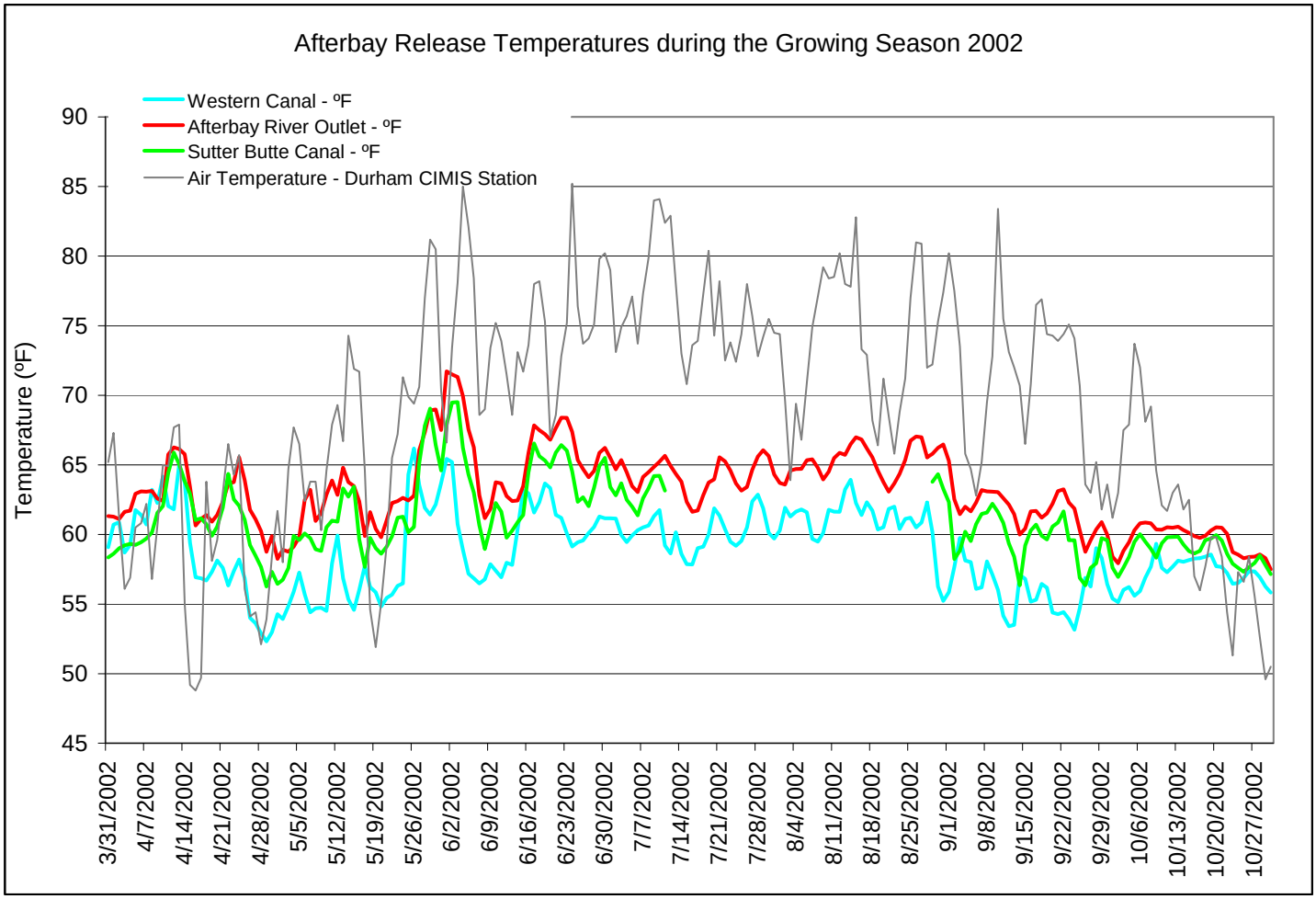


Figure D.2 Thermalito Afterbay Release Temperatures During Growing Season 2002

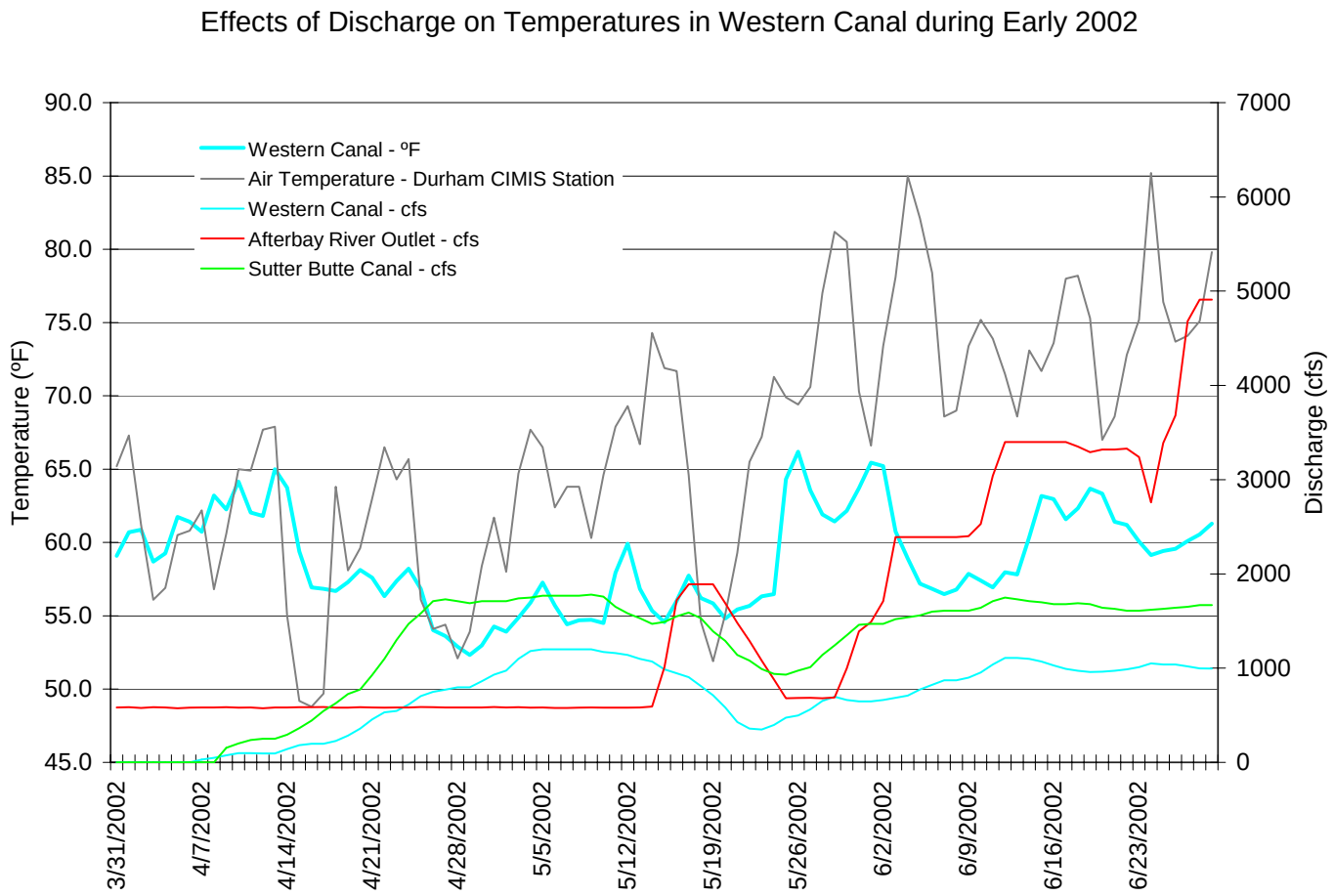


Figure D.3 Effects of Discharge on Temperature in Western Canal in Early 2002

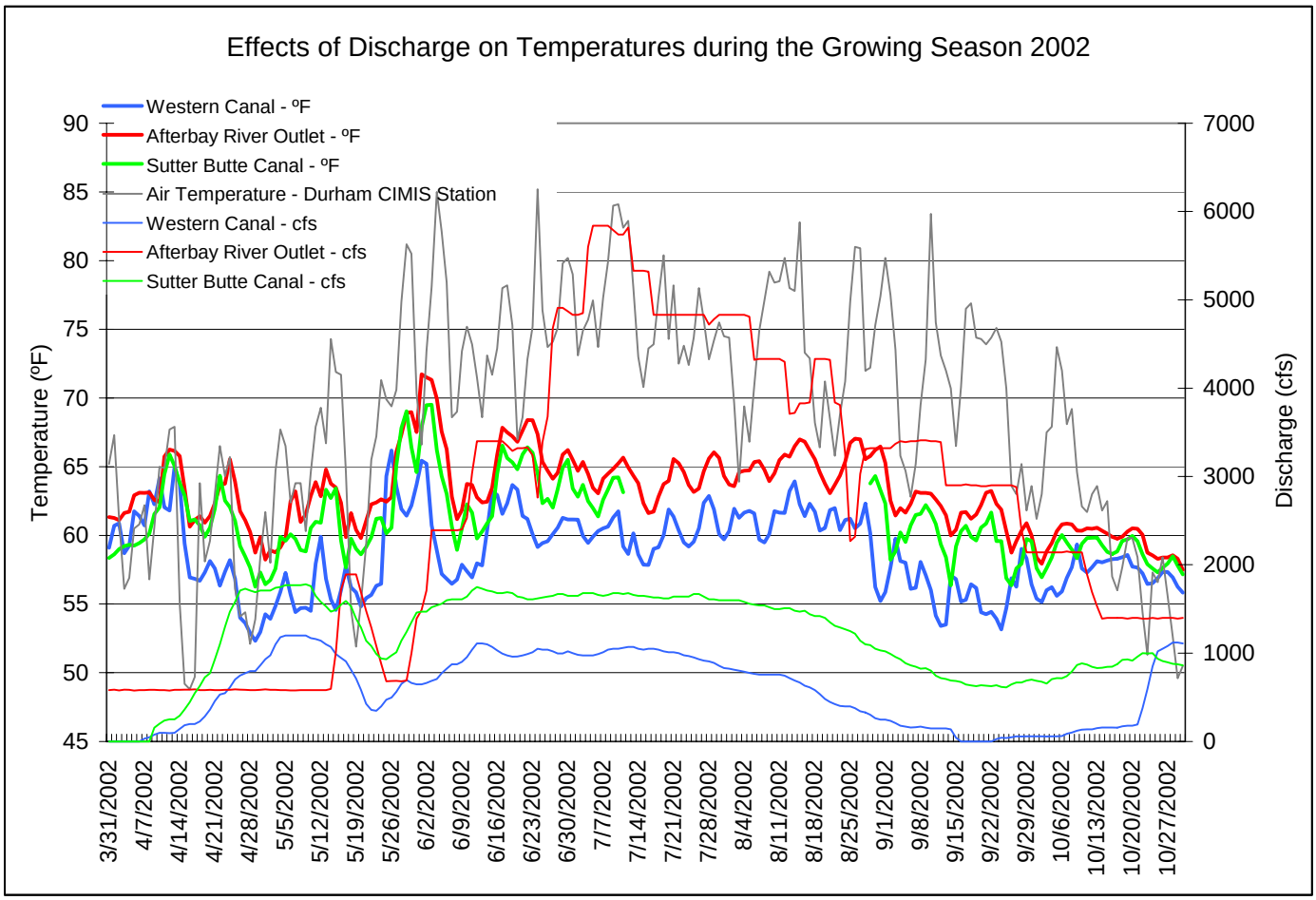


Figure D.4 Effects of Discharge on Temperature During Growing Season 2002

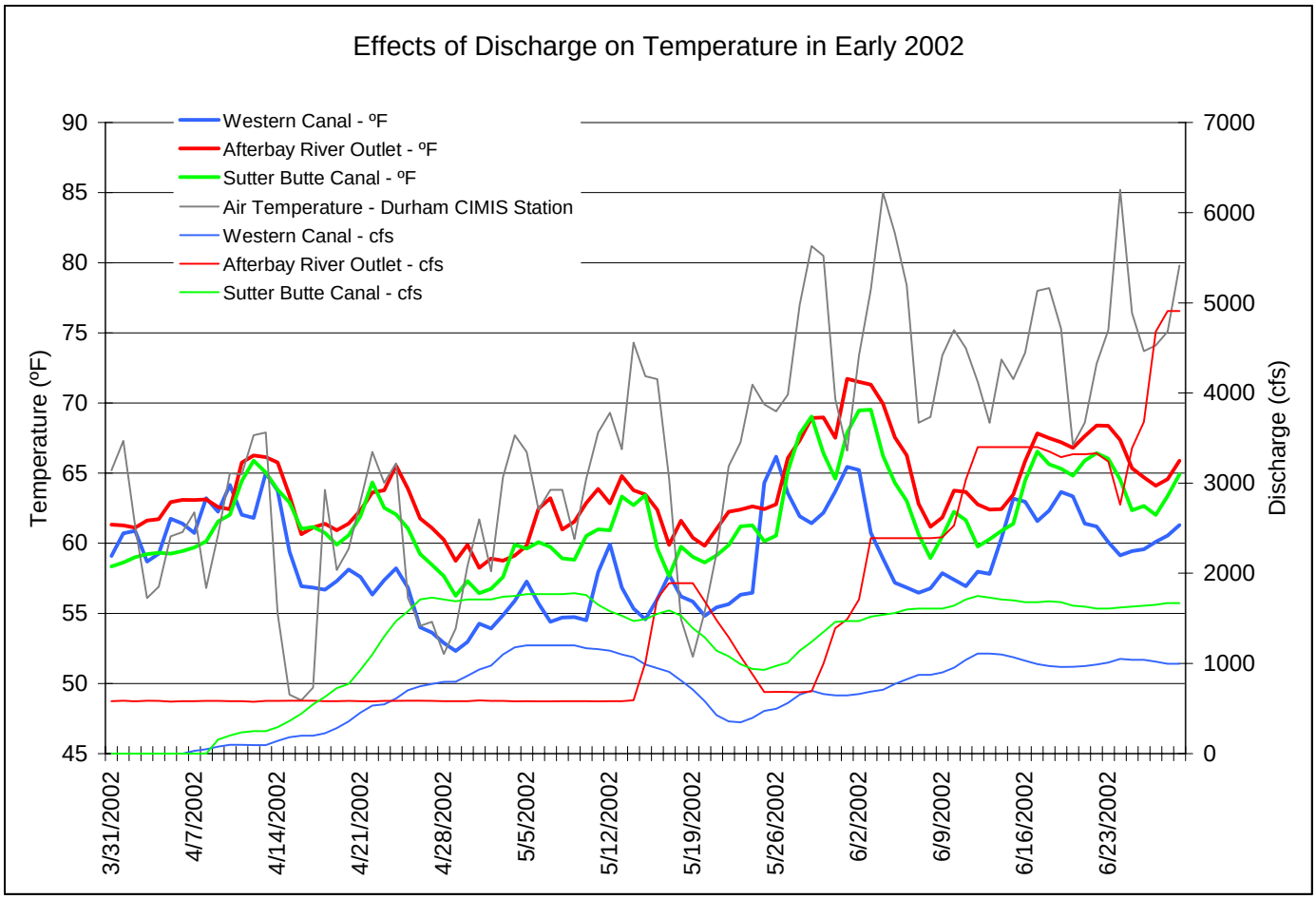


Figure D.5 Effects of Discharge on Temperature in Early 2002

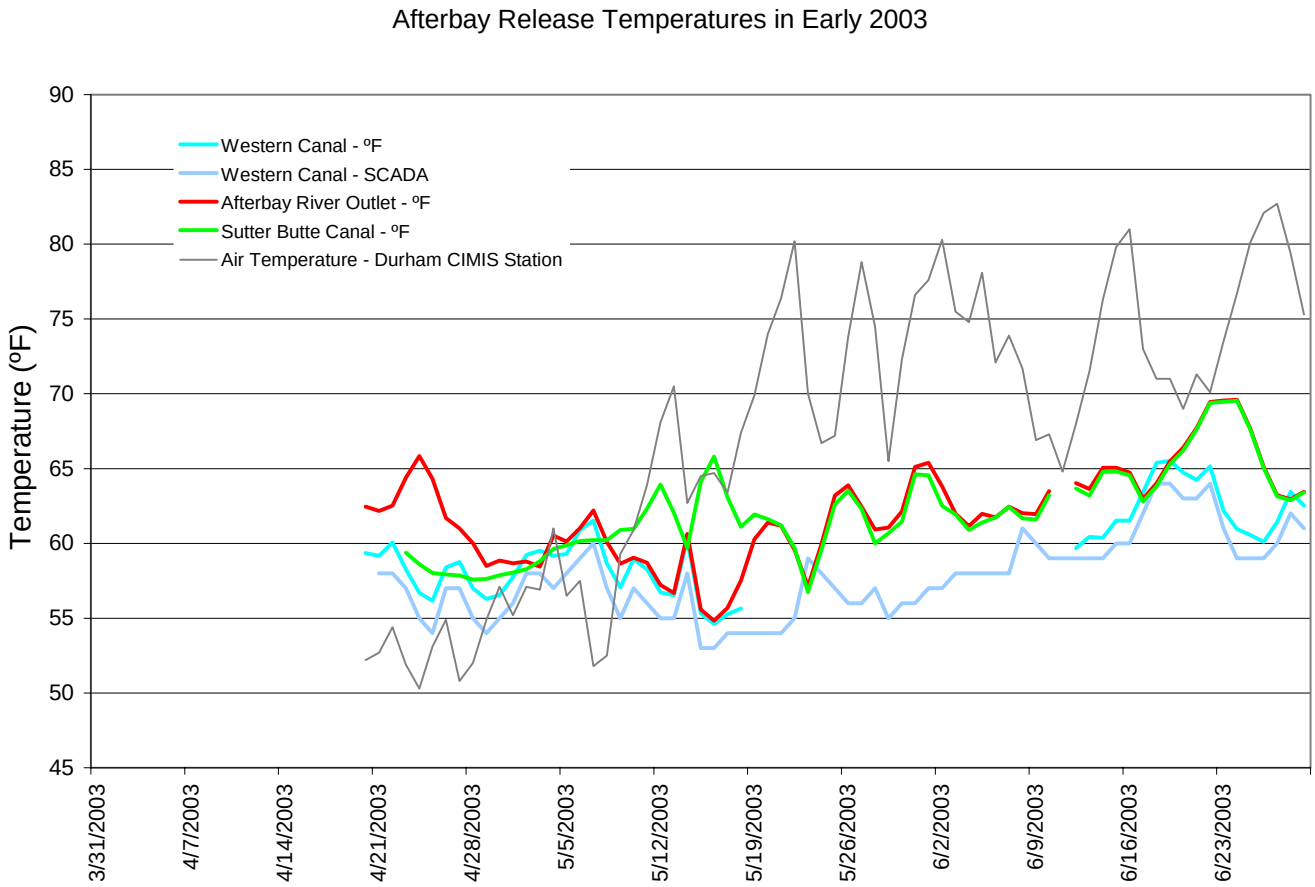


Figure D.6 Thermalito Afterbay Release Temperatures in Early 2003

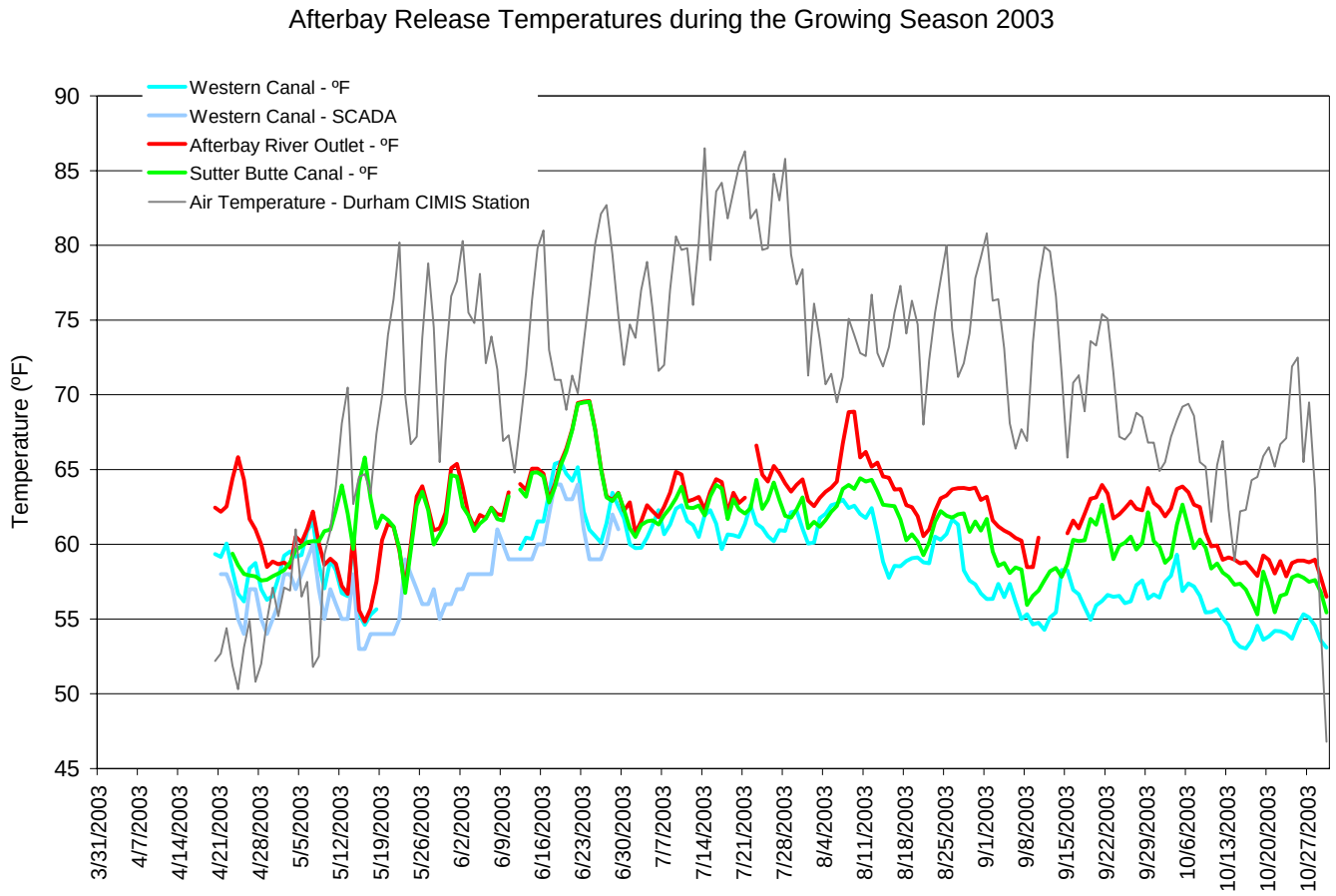


Figure D.7 Thermalito Afterbay Release Temperatures During Early Growing Season 2003

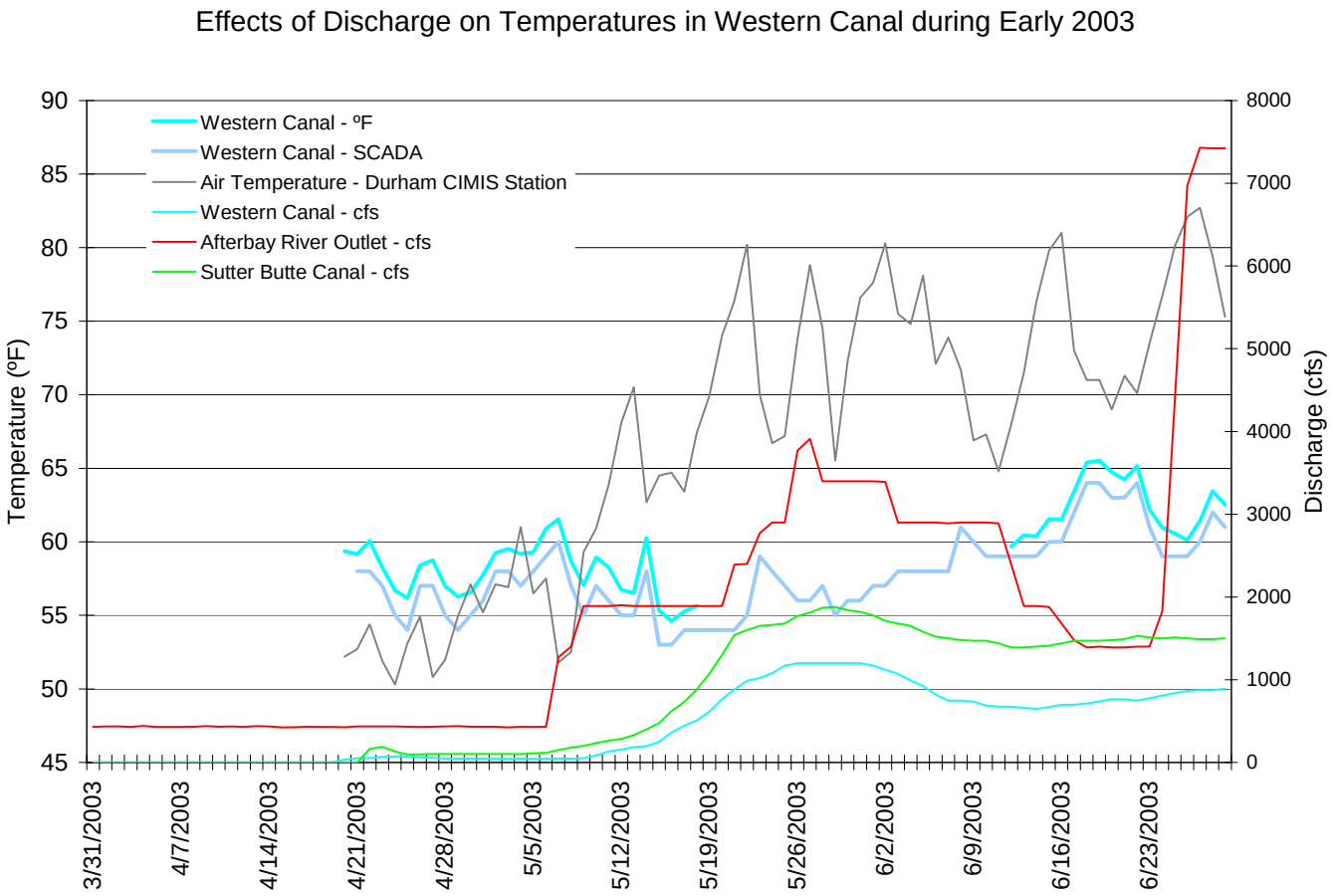


Figure D.8 Effects of Discharge on Temperature in Western Canal in Early 2003

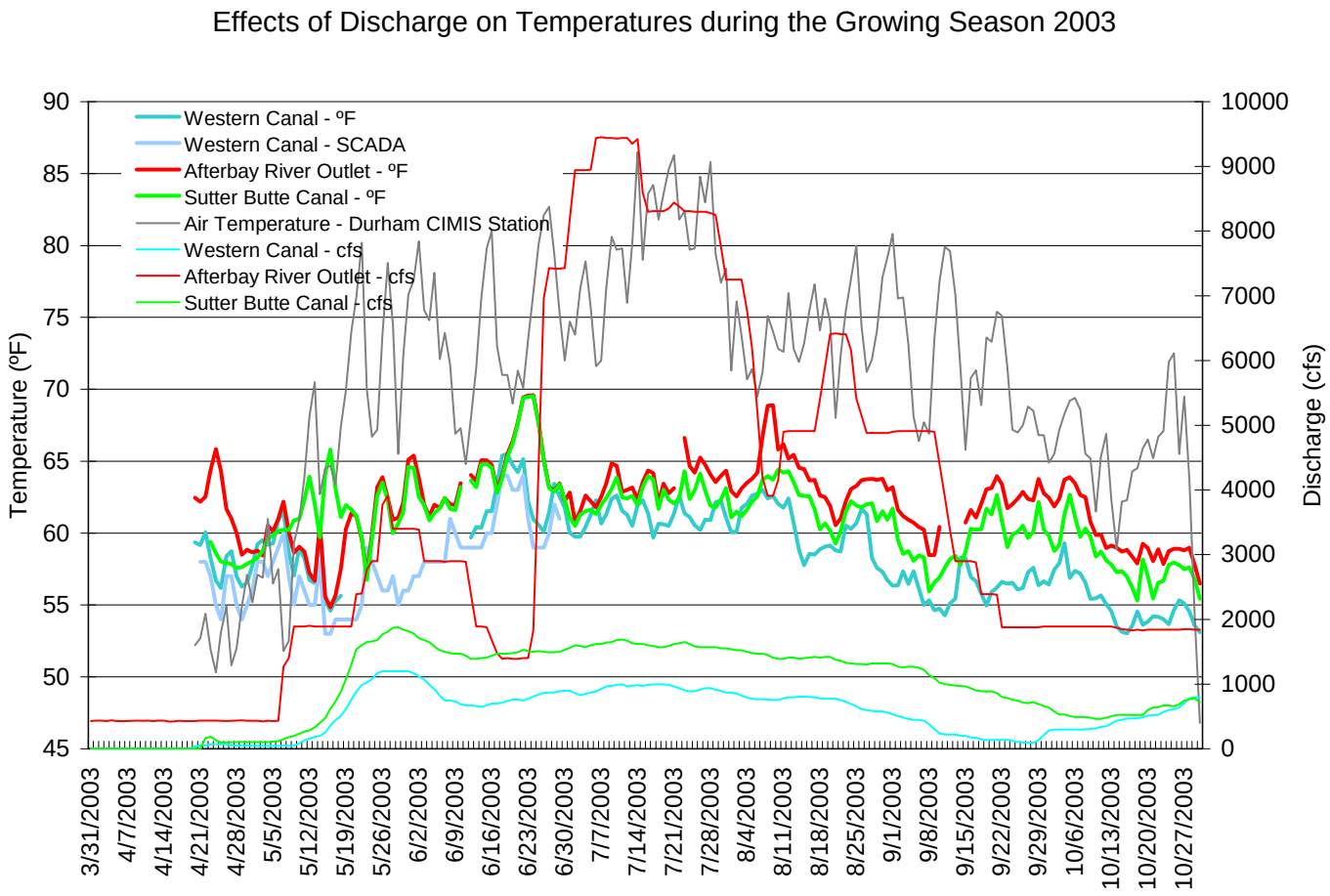


Figure D.9 Effects of Discharge on Temperature during Growing Season 2003

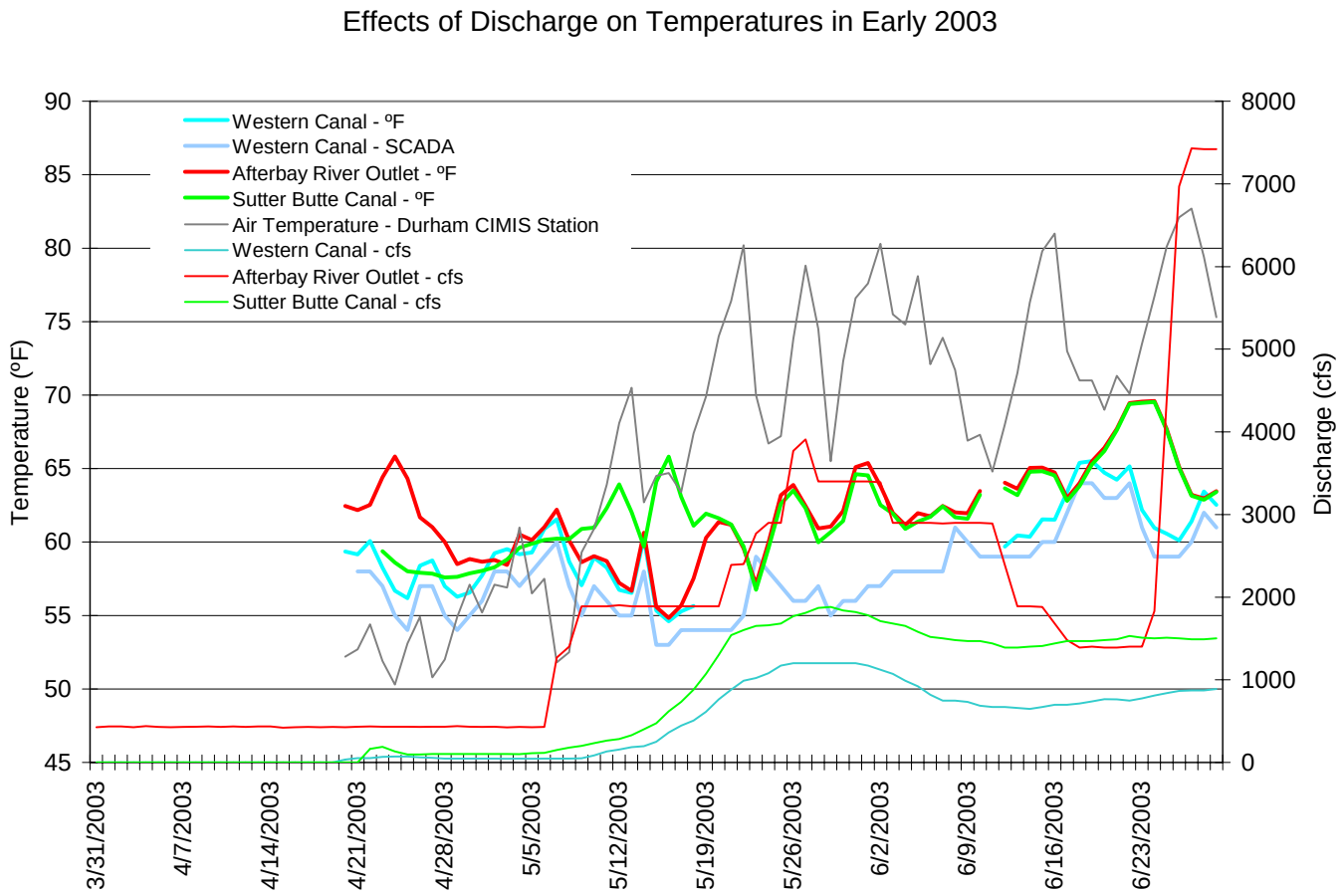


Figure D.10 Effects of Discharge on Temperature in Early 2003

Appendix E
Evaluation Tables

Description of Each Option Discussed During Brainstorming Meeting

Reconnaissance Level Feasibility Evaluation of Options Identified for Thermalito Afterbay Temperature Improvements during April 21, 2004 Brainstorming Meeting

	Capital Cost	Environmental	Recreation	Operational	Power	Pros	Cons
A. Convey Cold Water to Thermalito Afterbay Outlet							
A.1 Route some or all of the water, to be released to the river, down the low flow channel rather than through the Thermalito Complex (May 1 through June 30)	N/A			Yes	Yes /c/, /d/		
A.2 Construct canal outside of TAB to FR	C	Yes /a/	No	Yes	Yes /d/		
A.3 Install a suite of buried pipes in the Thermalito Afterbay to convey water directly from the Thermalito Power Plant to an area in the afterbay near the outlet structure.	C	Yes /b/		Yes	No		
A.4 Dredge an underwater conveyance channel along the thalweg of TAB to the outlet (requires facilities to "lift" into outlet)	C	Yes /b/		Yes	No		
A.5 Install temperature curtain (to cool water) on the east side of Thermalito Afterbay	C		Yes	No	No		
A.6 Construct canal outside of Thermalito Afterbay to transport water into the aferbay at another location (presumably southeastern)	C	Yes /a/	No	No	No		
B. Convey Warm Water to Agricultural Diversion Canals							
B.1 Draw warmer water for agricultural diversions	N/A	No	No	Yes	No		
B.2 Install baffles to warm water in Thermalito Afterbay	C	Yes /b/	Yes	No	No		
B.3 Install temperature curtain to warm water on west side of Thermalito Afterbay	C	Yes /b/	Yes	No	No		
B.4 Relocate Sutter Butte Canal Outlet		Yes /b/		No	No		
B.5 Relocate Richvale Canal Outlet and Western Canal Outlet		Yes /b/		No	No		
C. Increase Water Residence Time in Thermalito Afterbay							
C.1 Use baffles to re-direct return flow from conveyance structures.							
C.2 Change agricultural demand to allow longer residence time	N/A	No	No	No	No		
C.3 Manage TAB for agricultural flows (maximize residence time, TAB levels, and baffles to force cold water away from Western Canal)	N/A	N/A	N/A	Yes	Yes /e/		
C.4 Re-configure islands by connecting them in TAB to redirect water flow and increase residence time		Yes /b/	Yes	No	No		
D. Increase Water Temperature After Delivery to Agricultural Diversion Canals							
D.1 Install power generation units (no head) at agricultural canal outlets to increase temperature		Yes /b/		Yes	Yes /c/		
D.2 Install solar panels on canals with strip heaters in water		Yes /b/	Yes	Yes	Yes /c/		
D.3 Install stand pipes at agricultural canal outlets		Yes /b/		Yes	Yes /c/		
D.4 Pump warm air into water to increase water temperature at diversions		Yes /b/		Yes	Yes /c/		
D.5 Construct and operate a co-generation plant on Western Canal (such a facility could use rice straw waste) to increase water temperature		Yes /b/	Yes	Yes	Yes /c/		
D.6 Warm agricultural diversion water by building warming ponds in canals	N/A	N/A/	N/A/	N/A/	N/A/		
D.7 Place pool solar blankets on TAB		Yes	Yes	Yes	Yes		
D.8 Develop "shallow" pond to warm water near north end of afterbay		N/A	N/A	N/A	N/A		
D.9 Develop warming checks at turnouts –purchase for ponding	N/A	N/A	N/A	N/A	N/A		
D.10 Pump groundwater from the Tuscan aquifer layer.							
E. Change Thermalito Afterbay Inflow Temperature							
E.1 Operate Hyatt Intake structure to provide warmer water from May 1 through June 30	N/A		N/A	Yes	Yes		
E.2 Operate chiller to cool Feather River Fish Hatchery water for egg incubation from May 1 through Jun 30		Yes		Yes	Yes /e/		
E.3 Develop an alternative source of cold water for FRFH (i.e., Palermo Canal)		N/A	N/A	Yes	No		

/a/ Some impacts to vernal pools would be expected. Such footprint effects could be minimized and mitigated.

/b/ Would result in habitat effects during construction only.
/c/ Effects peaking operations only.
/d/ Effects pump-back operations.
/e/ Effects peaking and pump-back operations.
/f/ Capital Cost Ranges: (1) A<$1 million; (2) $1 million < B < $10 million; (3) C > $10 million.
/g/ The boxes highlighted in yellow indicate further analysis is required to make a reconnaissance level estimate.

Appendix F

Brief Description of Each Option Discussed in Brainstorming Meeting

A. Convey Cold Water to Thermalito Afterbay Outlet. The options in this category provide changes that allow the movement of water directly from the Thermalito Power Plant to either the Feather River or an area in the afterbay near the river outlet.

1. Route some or all of the water, to be released to the river, down the low flow channel rather than through the Thermalito Complex (May 1 through June 30). While this option does not provide changes in the afterbay, it allows some of the water that is intended to be released to the river to bypass the afterbay altogether. Therefore, this option would tend to result in lower water temperatures throughout the low flow channel as well as downstream of the afterbay. However, as noted earlier in the text, this option may not have much impact on water temperatures in the afterbay during periods when ambient temperatures are low.
2. Construct a canal outside of the Thermalito Afterbay to convey water directly from the Thermalito Power Plant to the Feather River. Water would be conveyed directly from the tailrace of Thermalito Pumping-Generating Plant directly into the Feather River thereby bypassing transport through Thermalito Afterbay; and as a result water residence time would increase, or the water would be conveyed to an area in the afterbay near the river outlet. Both alternatives achieve the objective of reducing residence time in the afterbay.
3. Install a suite of buried pipes in Thermalito Afterbay to convey water directly from the Thermalito Power Plant an area in the afterbay near the river outlet.
4. Dredge an underwater conveyance channel along the thalweg of Thermalito Afterbay to the outlet. The deepest part of Thermalito Afterbay would be dredged to create a channel that could convey the coldest water available in the afterbay
5. Install a temperature curtain (to cool water) along the east side of Thermalito Afterbay. Construct a structure along the eastern edge of Thermalito Afterbay that would separate water released from the Thermalito Power Plant from the rest of the afterbay. The water would enter the afterbay near the river outlet.

B. Convey Warm Water to Agricultural Diversion Canals. This set of options consider ways to either warm water before it enters the afterbay diversions or move the points of diversion to a location in the afterbay where warmer water is likely to reside.

1. Draw warmer surface water for agricultural diversions. This option would involve the installation of structures to selectively divert water at different elevations within the afterbay at the agricultural diversions.
2. Install baffles to warm water in Thermalito Afterbay.
3. Install temperature curtain to warm water on west side of Thermalito Afterbay. The option involves the construction of a structure along the west side of the afterbay that would separate water that is diverted from water that remains in

the afterbay. This option essentially moves the points of diversion for agricultural uses to a location (or locations) in the afterbay where warmer water may reside.

4. Physically relocate Sutter Butte Canal Outlet to another location in the afterbay.
5. Physically relocate Richvale Canal Outlet and Western Canal Outlet.

C. Increase Water Residence Time in Thermalito Afterbay. This set of options is designed to change the amount of time that water resides in the afterbay. By increasing residence time, water will tend to warm.

1. Install baffles to re-direct flow coming from a conveyance structure. This option would be linked to options that either separate warm or cold water.
2. Change agricultural demand to allow longer residence time. This option would have agricultural diverters coordinate the increase the amount of time that water would reside in the afterbay. In essence, water would be allowed to enter the afterbay and remain there for some period of time before diversions are increased.
3. Manage Thermalito Afterbay for agricultural flows (maximize residence time, levels, and baffles to force cold water away from Western Canal). A combination of operational and structural changes could increase water temperatures during summer months – note that during early Spring months if ambient air conditions are cool structural changes will not be effective
4. Re-configure islands by connecting them in Thermalito Afterbay to redirect water flow and increase residence time. A series of warm and cold water pools would be created to help with agricultural diversions and aquatic species, respectively

D. D. Increase water temperature after delivery to agricultural diversion canals.

1. Install power generation units (no head) at canal outlets to increase temperature. The generating units would most likely be run-of-the-river and installed at each canal outlet.
2. Install solar panels on canals with strip heaters in water. Strip heaters would be placed in Thermalito Afterbay near the canal outlets; the strip heaters would receive solar energy to warm up afterbay water
3. Install stand pipes at agricultural canal outlets. Water would be pumped into the stand pipes and allowed to “trickle” down the outside. The trickle would increase the surface area and subject more water to ambient temperature.
4. Pump warm air into water to increase water temperature. A heating mechanism would pump hot air to warm Theramalito Afterbay water
5. Co-generation plant on Western Canal (such a facility could use rice straw waste) to increase water temperature. Install a co-generation plant that would use the heat generated from burning a fuel (such as rice straw). Cooling water would be supplied for the plant from Western Canal; once heated, the water would be returned back to the canal for application to fields.

6. Warm agricultural diversion water by building warming pond in the canal. This option would involve building a warming pool near or in the diversion district's system that would allow water to warm up before delivery to service area.
7. Place pool solar blankets on Thermalito Afterbay. Install solar heating blankets on Thermalito Afterbay to warm the water near the agricultural diversions
8. Develop "shallow" pond to warm water near the north end of the afterbay.
9. Develop warming checks at turnouts –purchase for ponding. Each diverter could develop warming checks (in addition to the primary warming check, i.e., Check 1) by retiring a certain amount of acreage to pond warm water.
10. Pump groundwater from the Tuscan aquifer layer.

E. E. Change Thermalito Afterbay Inflow Temperature

1. Operate Hyatt Intake structure to provide warmer water from May 1 through June 30. Operating the higher temperature objectives for the river and/or hatchery would allow warmer water to be drawn from Lake Oroville and diverted into Thermalito Afterbay.
2. Operate chiller to cool Feather River Fish Hatchery water from May 1 through June 30. The existing refrigeration unit would be operated at the fish hatchery to help meet temperature objectives for egg incubation when warmer water may be necessary for agricultural diversions.
3. Develop an alternative source of cold water for Feather River Fish Hatchery (i.e. Palermo Canal). A portion of the Palermo Canal diversion could be used to provide very cold water for mixing at the Feather River Fish Hatchery .

References

1. DWR's SCADA database system (Supervisory Control and Data Systems)
2. United States Geological Survey's Thermalito Afterbay Outlet temperature gage